SEE FOLLOWING NOTE

VOIR NOTE CI-APRÈS

PARTS OF THE ORIGINAL DOCUMENT ARE OF POOR REPRODUCTIVE QUALITY.

MICROMEDIA LIMITED HAS ATTEMPTED TO PRODUCE THE BEST POSSIBLE COPY.

CERTAINES PARTIES DU DOCUMENT ORIGINAL SONT DE PIÈTRE QUALITÈ DE REPRODUCTION.

MICROMEDIA LTEE A ESSAYEE DE PROCURER LE MEILLEUR EXEMPLAIRE POSSIBLE.

Canada Alberta

FOREST RESOURCE DEVELOPMENT AGREEMENT
ENTENTE SUR LA MISE EN VALEUR DES RESSOURCES FORESTIERES

Canada Alberta

The Canada–Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada–Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.

The Canada–Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.

Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

The Agreement comprises three programs: Reforestation; Applied research, technology transfer and opportunity identification; and Public information, evaluation and administration. These programs are managed by a joint Directorate and are implemented by Forestry Canada and the Alberta Forest Service.

L'Entente Canada–Alberta sur la mise en valeur des ressources forestières est auxiliaire à l'Entente Canada–Alberta sur le développement économique et régional, qui vise à assurer la coordination et la coopération des deux gouvernements relativement au développement économique de l'Alberta.

L'Entente Canada–Alberta sur la mise en valeur des ressources forestières est financée à parts égales par les gouvernements du Canada et de l'Alberta, et a cours du 1er avril 1984 au 31 mars 1989.

Ses objectifs principaux sont assurer la disponibilité à long terme de réserves de bois; optimiser leur utilisation; et contribuer à la croissance et la diversification de l'économie de la province.

L'Entente comprend trois programmes: Reboisement; Recherche appliquée, transferts de connaissances techniques et relevé des occasions; et Information, évaluation et administration. Ces programmes sont gérés par un Bureau de direction conjoint, et mis en oeuvre par Forêts Canada et le Service forestier de l'Alberta.

For more information, please call or write:

Pour de plus amples informations, veuillez vous adresser à:

Forestry Canada
Northern Forestry Centre
5320 - 122 Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435-7210

OR/OU Alberta Department of
Forestry, Lands & Wildlife
9915 - 108 Street
Edmonton, Alberta
T5K 2C9
Telephone: (403) 427-3583

92-04065/

ENVIRONMENTAL IMPACTS OF VEGETATION MANAGEMENT BY MECHANICAL AND CHEMICAL (HEXAZINONE) METHODS INCLUDING RESIDUE CHEMISTRY

MARCH 1990

S.S. Sidhu and J.C. Feng

This publication is based on a joint research project by Forestry Canada and the Alberta Forest Service pursuant to the Canada-Alberta Forest Resource Development Agreement

Project # 1412-97

DISCLAIMER

The study on which this report is based was funded under the Canada/Alberta Forest Resource Development Agreement. The views, conclusions, and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Forestry Canada or the Alberta Forest Service.

This report is a compendium of published and unpublished information generated from various components of the Canada-Alberta FRDA study at the Grande Prairie site. The unpublished parts of the report did not undergo a scientific review process and may appear as scientific publications following an appropriate review.

Minister of Supply and Services Canada 1991
Catalogue No.: FO42-91/99-1991E
ISBN: 0-662-18706-7

Additional copies for this publication are available at no charge from:

Forestry Canada
Regional Development
5320 - 122 Street
Edmonton, Alberta
T6H 3S5
Telephone: (403) 435-7210

or

Forestry, Lands and Wildlife
Forest Industry Development Division
108th Street Building
#930, 9942 - 108th Street
Edmonton, Alberta
T5K 2J5
Telephone: (403) 422-7011

Section 1

EXECUTIVE SUMMARY

A study on the environmental impact of vegetation management methods in a mixedwood cutover was carried out from 1985 to 1990 under the Canada-Alberta Forest Resources Development Agreement. The vegetation management treatments included two rates of a granular formulation of the active ingredient (ai) hexazinone (PRONONE 10G, 2 and 4 kg ai/ha) and mechanical methods [double disking (DD), disk trenching (DT), brush saw (BS)] for site preparation and crop release. We evaluated the impact of these methods on the vegetation composition, structure and dynamics, developed environmental impact and residue and fate data for hexazinone as PRONONE 10G and residue analysis techniques. We also evaluated herbicide application technology and determined the influence of hexazinone application on the nutrient dynamics in plants and soil and mycorrhizae.

Site preparation treatments were applied in the fall of 1986 and crop release treatments in the spring 1989. For the most part, the results presented in this report are applicable to site preparation treatments involving fall application of PRONONE 10G and spring application of mechanical treatments. Detailed results on various components of the study are presented in appropriate sections of the report. Some of the important conclusions and recommendations in the report are as follows:

Conclusions:

1. Upto 20% of foliar damage in aspen can result from insect and disease damage for short durations.

2. Low herbicide treatment (LH, 2 kg hexazinone/ha) had marginal control of woody and herbaceous vegetation except *Calamagrostis canadensis*. The 4 kg/ha (HH) treatment produced herbicide damage to a range of plant species. The effect of all treatments reached the peak by the second growing season following the application. The efficacy of different treatments in controlling vegetation was in the order: DD > HH+DT > HH > DT+LH > LH.

3. Based on ai release studies it is estimated that release of hexazinone from PRONONE 10G granules would be within 1-2 weeks in northern Alberta when applied during the label-specified time of application.

4. Amounts of hexazinone residues found in soil leachate as well as in surface water and sediment in pools near the application site are unlikely to have any detrimental effect on the environment. They were 50,000-1,000,000 times lower than the reported LC_{50} and LD_{50} for fish and wildlife.

5. Hexazinone and its metabolites do accumulate and dissipate in vegetation and small mammals. Most accumulation occurred during the first year after application. Detected concentrations were much below the acute toxicity levels for various animals.

6. Hexazinone at 1 and 2 kg/ha have no or very little effect on mycorrhizal development in white spruce and lodgepole pine under field conditions.

7. No long term negative effect of hexazinone is expected on the survival of mycorrhizal inoculum and development of mycorrhizal infections in white spruce and lodgepole pine at 1-4 kg/ha rates under field conditions.

8. The effect of PRONONE 10G on the nutrient status in foliage declined by the end of the preliminary results second growing season (1988) and by 1989 (third growing season) there were no significant differences in the nutrient status of foliage from control and herbicide treated plots.

9. Nutrient balance (perticularly N, S, and Ca) has been altered up to 2 years after herbicide application, however the implications of herbicide on site productivity are not clear at this time. Continuation of the study over the next 5-8 years will clarify.

Recommendations:

1. In assessing the effect of the fall applied PRONONE on vegetation control, first year assessments can be skipped for effective use of resources in high cost environmental assessments. Where effective control of woody species is desired, 2 kg hexazinone/ha rate should be excluded in a fall application.

2. The woody stem control data should be analyzed in relation to the establishment and growth of crop seedlings for the third, fifth and eighth years following the site and crop release treatments of 1986 and 1989 (1989/90, 1991/92, and 1995/96) and cost/benefit analysis of treatments be performed to establish practical guidelines for vegetation management.

3. All cover data and terrain disturbance data be related to crop seedling growth and possible losses of soil and soil nutrients before making final recommendations on vegetation management by mechanical methods alone or in combination with herbicides.

4. The vegetation should be sampled for studying the successional trends in the future at 5 and 8 years after treatments and relate these changes to nutrient dynamics in soil and crop seedlings growth to assess the impacts of long term vegetation changes due to vegetation management.

5. The application technologies should be developed further to deliver uniformly and correctly calibrated amounts to ensure homogenous distribution of granular herbicides at the ground level.

6. The logarithmic sprayer should be used in small plot, dosage-response trials for the liquid formulations of forestry herbicides with three or more replicates.

7. In estimating the dissipation rate of a liquid herbicide in soils, that the glass-jar sampling method be used between zero-time immediately after spraying and the first rainfall, followed by the conventional corer method for subsequent soil samplings.

8. The new analytical method should be submitted to the National Check Sample Program of the Canadian Association of Pest Control Officials (CAPCO) for interlaboratory evaluation and if found reliable, be transferred to analytical laboratories, researchers, and the federal and provincial regulatory agencies.

9. As recommended jointly by the Forestry Canada, Alberta Environment, and Alberta Forest Service that the soil samplings be continued until the residues of hexazinone are reduced to non-detectable levels in two consecutive samplings.

10. It is recommended that soil dynamics studies be carried out at 3, 5 and 8 years intervals following the herbicide application.

CONTENTS

Section			Page
1.	EXECUTIVE SUMMARY		iii
2.	INTRODUCTION		1
3.	OBJECTIVES		2
4.	VEGETATION CHANGES AND ENVIRONMENTAL IMPLICATIONS		4
	4.1	STUDY AREA	4
	4.2	PLOT LAYOUT AND EXPERIMENTAL DESIGN	4
	4.3	VEGETATION SAMPLING AND ANALYSIS OF DATA	11
		4.3.1 Symptomology and Evaluation of Herbicide and Insect/Disease Damage	11
		4.3.1.1 The herbicide	11
		4.3.1.2 Mode of Action	13
		4.3.1.3 Methods of assessing herbicide damage	14
		4.3.2 Stem Density	15
		4.3.2.1 Analysis of stem density data	15
		4.3.3 Vegetation Cover	27
		4.3.3.1 Analysis of the species presence and cover data	28
	4.4	RESULTS AND IMPLICATIONS	29
		4.4.1 Symptomology and Evaluation of Herbicide and Insect and Disease Damage	29
		4.4.2 Stem Density Results	34
		4.4.3 Vegetation Cover and Species Presence	41
		4.4.3.1 Species presence, richness, and plot similarity	41

4.4.3.2 Vegetation cover 45

4.5 CONCLUSIONS 75

5. DEVELOPMENT OF APPLICATION, SAMPLING, AND ANALYTICAL TECHNOLOGIES 81

5.1 DETERMINATION OF GRANULE DISTRIBUTION FROM AERIAL AND GROUND APPLICATION 81

5.1.1 Background 81

5.1.2 Materials and Methods 82

5.1.2.1 Ground applicator tests 82

5.1.2.2 Aerial applicator tests 83

5.1.3 Results and Discussion 84

5.1.3.1 Granule size variation tests 84

5.1.3.2 Ground applicator tests 84

5.1.3.3 Aerial applicator tests 88

5.1.3.4 Estimates for optimal sampling 88

5.2 CROSSWIND EFFECT ON ISOLAIR AERIAL GRANULE APPLICATOR 90

5.3 PERFORMANCE OF ISOLAIR BUCKET SPREADER IN FIELD AERIAL APPLICATION OF PRONONE 10G 91

5.4 PERFORMANCE OF GRANUL-AIR APPLICATOR IN FIELD GROUND APPLICATION OF PRONONE 10G 92

5.5 DETERMINATION OF HEXAZINONE DEPOSITION FROM A LOGARITHMIC SPRAYER 94

5.5.1 Background 94

5.5.2 Materials and Methods 95

5.5.2.1 Site description 95

5.5.2.2 Experimental plots 95

5.5.2.3 Herbicide application and logarithmic sprayer 95

5.5.2.4 Deposit collection 96

5.5.2.5 Residue analysis 96

5.5.2.6 Statistical analysis 96

5.5.3 Results and Discussion 98

5.5.4 Summary 99

5.6 SAMPLING FOR ZERO-TIME HEXAZINONE RESIDUES IN FOREST SOILS FOR DISSIPATION STUDY 100

5.6.1 Background 100

5.6.2 Materials and Methods 101

5.6.2.1 Experimental site and herbicide application 101

5.6.2.2 Soil sampling 101

5.6.2.3 Residue analysis and reporting 102

5.6.3 Results and Discussion 102

5.7 NEW ANALYTICAL METHODS FOR DETERMINATION OF HEXAZINONE RESIDUES IN SOIL AND VEGETATION SAMPLES .. 105

5.7.1 Background 105

5.7.2 Microcolumn Method for Determination of Hexazinone in Soils 105

5.7.2.1 Sample preparation 105

5.7.2.2 Microcolumn preparation 105

5.7.2.3 Sample cleanup 105

5.7.2.4 Gas chromatography 106

5.7.2.5 Summary 107

5.7.3 Microcolumn Method for Determination of Hexazinone in Vegetation 107

5.7.3.1 Sample preparation 107

5.7.3.2 Microcolumn preparation 107

5.7.3.3 Sample cleanup 107

5.7.3.4 Gas chromatography 108

5.7.3.5 Summary 108

6. HEXAZINONE RELEASE AND ENVIRONMENTAL FATE 113

6.1 RELEASE OF HEXAZINONE FROM PRONONE 10G GRANULES EXPOSED TO SIMULATED RAINFALL UNDER LABORATORY CONDITIONS 113

6.1.1 Background 113

6.1.2 Materials and Methods 114

6.1.2.1 Simulated rainfall apparatus and experimental procedure 114

6.1.2.2 Standard and extracting solutions 114

6.1.2.3 Sample preparation 116

6.1.2.4 Gas chromatography 116

6.1.3 Results and Discussion 116

6.2 DETERMINATION OF HEXAZINONE RESIDUES AND RELEASE FROM A GRANULAR FORMULATION UNDER FOREST CONDITIONS 119

6.2.1 Background 119

6.2.2 Materials and Methods 119

6.2.2.1 Experimental 119

6.2.2.2 Granule fortification and coating 120

6.2.2.3 Residue extraction and sample preparation 120

6.2.2.4 Gas chromatography 121

6.2.3 Results and Discussion 121

6.2.3.1 Extraction methods 121

6.2.3.2 Hexazinone release 122

6.3 HEXAZINONE RESIDUES AND DISSIPATION IN SOIL LEACHATE. 124

6.3.1 Background 124

6.3.2 Materials and Methods 125
6.3.2.1 Experimental site and herbicide application 125
6.3.2.2 Soil leachate collection 125
6.3.2.3 Residue analysis 127
6.3.2.4 Statistical analysis 127
6.3.3 Results and Discussion 128
6.4 PERSISTENCE AND MOBILITY OF HEXAZINONE IN SOILS 130
6.4.1 Background 130
6.4.2 Materials and Methods 132
6.4.2.1 Site description 132
6.4.2.2 Experimental design 132
6.4.2.3 Granule fortification and coating 133
6.4.2.4 Residue extraction, cleanup, analysis, and reporting 133
6.4.3 Results and Discussion 134
6.5 HORIZONTAL AND VERTICAL VARIATION OF HEXAZINONE IN SOILS 139
6.5.1 Background 139
6.5.2 Materials and Methods 139
6.5.2.1 Site description and herbicide application 139
6.5.2.2 Soil sampling to determine the general distribution of hexazinone in the treatment plots 143
6.5.2.3 Deep-pit soil sampling to determine the degree of vertical leaching of hexazinone 143
6.5.2.4 Sample preparation and residue analysis 143
6.5.3 Results and Discussion 143
6.5.3.1 Persistence and uniformity of hexazinone one year after treatment 143

6.5.3.2 Deep soil sampling for hexazinone leaching 144

6.6 HEXAZINONE RUNOFF IN EPHEMERAL AND PERMANENT STREAMS 144

6.7 UPTAKE AND DISSIPATION OF HEXAZINONE IN VEGETATION .. 149

6.7.1 Background 149

6.7.2 Methods 149

6.7.3 Results and Implications 150

7. EFFECTS OF HEXAZINONE ON MICROORGANISMS 161

8. EFFECT OF HEXAZINONE ON NUTRIENT STATUS IN FOLIAGE, AND SOILS NUTRIENT DYNAMICS 163

8.1 FOLIAR NUTRIENTS 163

8.1.1 Introduction 163

8.1.2 Materials and Methods 163

8.1.3 Results and Conclusions 164

8.2 SOIL NUTRIENT DYNAMICS 165

8.2.1 Introduction 165

8.2.2 Materials and Methods 166

8.2.3 Results and Discussion 167

8.2.4 Conclusions 170

9. SUMMARY AND RECOMMENDATIONS 171

ACKNOWLEDGEMENTS 176

REFERENCE 176

APPENDIX A: Plant Species Present in Treatment Plots 183

APPEXDIX B: Percent Frequency of Cover Classes 186

APPENDIX C: Nutrient analysis of foliage and twigs of selected species from Pronone-treated and control plots of the Grande Prairie study, in mg/kg (except total N) of material and blank subtracted 202

TABLES

4-1. Percent (n = 60) stems (top 20 cm) in each foliar damage class in herbicide-treated and control plots at various times during 1987. Plots were treated on 28 August, 1986 16

4-2 Percent stems in each foliar damage class in herbicide, mechanical, and control plots on 28 June 1988. Plots were treated on 28 August 1987 22

4-3 Percent stems in each foliar damage class in herbicide and mechanically tested and control plots on 11 July 1989. Plots were treated on 28 August, 1987 23

4-4 Frequency and intensity of *Cibornia whetzellii* (Seaver) in various treatment plots and blocks of Vegetation Management (Site Preparation) Study at Grande Prairie, 12 June 1986. Assessments were done prior to any treatment 24

4-5 Phenological summary 1987 for aspen (Populus tremuloides) from control and herbicide-treated plots 25

4-6. Average densities of woody stems (> 50 cm) in control, herbicide and mechanicaly site preparation Blocks 1 to 3 of the Grande Prairie study 26

4-7 Aspen densities (≥ 50 cm) (average and coefficient of variation) in controls and herbicide and mechanically treated plots in Blocks 1 to 3 (site preparation) of the Grande Prairie Study 35

4-8 Stem densities (stems/ha) for two height classes (50-150 cm and > 150 cm) of aspen in control, and herbicide alone and plus mechanically treated plots in Blocks 1 to 3 (site preparation) of the Grande Prairie study 36

4-9 Summary of stem density data analyses by Friedman's non-parametric test for Randomised Block Analysis of Variance (P = 0.05) and Tukey's Procedure for ranked data in a randomized complete block analysis of means separation (P = 0.05) 37

4-10 Pre- (1986) and Post-treatment average stem density of live stems over 50 cm high in control, in herbicide and mechanically treated plots of the Grande Prairie site 38

4-11 Species richness and number of species in control and herbicide-treated plots in 1986 to 1989 42

4-12 Vegetation dissimilarity based on species frequency[a] and Cover[b] 43

4-13 Frequency of occurrence of leading species by year and treatment, with 95% binomial confidence limits 46

4-14 Cover class frequencies[a] by year for vegetation strata, control treatment 53

4-15 Cover class frequencies[a] by year for vegetation strata, low herbicide treatment 54

4-16 Cover class frequencies[a] by year for vegetation strata, high herbicide treatment 55

4-17 Percent surface disturbance in control and treated plots - pooled data from all blocks, 1987 61

4-18 Total vegetation cover in seedling competition quadrats by percent frequency of quadrats in each cover class, 1987 61

4-19 Cover class frequencies[a] by year for leading species[b], control treatment 62

4-20 Cover class frequencies[a] by year for leading species[b], low herbicide treatment (2 kg hexazinone/ha) 65

4-21 Cover class frequencies by year for leading species, high herbicide treatment (4 kg hexazinone/ha) 67

4-22 Frequency of quadrat changes of two or more cover classes for species with a median cover class of 5% or more in one of three years (360 quadrats/year) in one or more of the treatments 69

4-23 Cover Class Frequencies by Substrate Type for Leading Species in Mechanically Treated Plots (Method II), 1989 73

5-1 Percent frequency of granules of a ground application in weight classes at different delivery distances from the center of a truck-mounted rotary applicator .. 87

5-2 Mean of averaged (four trays) granule deposition at 1-m spacing within different portion of the distribution profile for aerial application of granules 90

5-3 Estimated optimal sample size (no. of collection trays) for aerial granule deposition in a 27-m swath width within expected ranges of variation and their probabilities (P) at 20- and 40-kg/ha application rates 91

5-4 Crosswind effect on the distribution of Pronone 10G granules applied by using helicopter-Isolair applicator 92

5-5 Distribution of Pronone 10G granules within the central 40 m of the 80-m wide plots applied with three overlapping swaths by helicopter-Isolair applicator 93

5-6 Distribution of Pronone 10G granules at each transect and their means for four separate plots treated at two different rates by using a tractor-mounted ground applicator, Granul-Air 94

5-7 Equations Illustrating Deposition of Hexazinone by Distance within a 2 X 50 m Plot Treated with a Backpack Logarithmic Sprayer 99

5-8 Hexazinone residue levels detected in soils at zero-time by means of a glass jar method, and at 0, 210, and 360 days after spraying by means of a corer method 103

5-9 Mean (n = 3) and overall percent recoveries of fortified hexazinone, metabolites A and B in soil 111

5-10 Mean percent recovery of hexazinone spiked at 1 ppm (μg/g dry weight) in different vegetation species by using the microcolumn method 112

6-1 Volume of water and time required for the simulated railfall tests 116

6-2 Total weight (mg) of hexazinone (a.i.) per g of granules and the calculated percent (%) a.i. release from PRONONE 10G formulation treated with simulated rainfall (cm) 117

6-3 Measurements and variations of the PRONONE 10G granule weight (mg), hexazinone weight (mg) and the percent (%) hexazinone content 118

6-4 Percent hexazinone release from PRONONE 10G granules in relation to cumulative rainfall (mm) and exposure time (days) 122

6-5 Estimation of the expected days required on the percent release of hexazinone from the PRONONE 10G granules by cumulative rainfall 124

6-6 Equations illustrating leaching and dissipation of hexazinone in soil water by time and volume of leachates at different depths treated with two rates of PRONONE 10G 130

6-7 Dissipation and leaching of hexazinone applied as Pronone 10G (2 kg ai/ha) in Grande Prairie soils (1986 - 1988) 135

6-8 Dissipation and leaching of hexazinone applied as Pronone 10G (4 kg ai/ha) in Grande Prairie soils (1986 - 1988) 136

6-9 Metabolite B detected in soils treated with 2 kg ai/ha Pronone 10G in Grande Prairie 137

6-10 Metabolite B detected in soils treated with 4 kg ai/ha Pronone 10G in Grande Prairie 138

6-11 Metabolite A detected in soils treated with 2 kg ai/ha Pronone 10G in Grande Prairie 140

6-12 Metabolite A detected in soils treated with 4 kg ai/ha Pronone 10G in Grande Prairie 141

6-13 Equations illustrating leaching and dissipation of hexazinone in soil by time at different depths at two rates of Pronone 10G treatments 142

6-14 Mean (n=5 per block) residue concentrations of hexazinone and metabolites, A and B, in soils of triplicated blocks one year after treated with PRONONE 10G at 2 kg ai/ha 145

6-15 Mean (n=5 per block) residue concentrations of hexazinone and metabolites, A and B, in soils of triplicated blocks one year after treated with PRONONE 10G at 4 kg ai/ha 145

6-16 Deep soil sampling for hexazinone residues two years after treatment with PRONONE 10G at 4 kg ai/ha rate 146

6-17 Deep soil sampling for hexazinone residues two years after treatment with PRONONE 10G at 2 kg ai/ha rate 146

6-18 Hexazinone concentration in surface water and sediments outside the area treated with Pronone 10G on 28-08-1986 in Grande Prairie 148

6-19 Hexazinone concentrations in surface water of new sampling sites established in 1988, outside the area treated with Pronone 10G on 28-08-1986 at the Grande Prairie Method II experimental area 148

6-20 Ratio of hexazinone toxicity (LC_{50}) and the maximum detected residues in surface water (Site No. 1) 149

6-21 *Average (±S) concentration of hexazinone residues in twigs of three browse species. The hexazinone was applied as Pronone 10G on 28 August 1986 152

6-22 Hexazinone residues (μg/g, dry wt.) in selected species during 1987-88 in samples from high herbicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots ... 153

6-23 Metabolite-B (μg/g, dry wt.) in selected species during 1987-88 in samples from high hebcicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots.... 155

6-24 Metabolite-A (μg/g, dry wt.) in selected species during 1987-88 in samples from high hebcicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots 157

6-25 Toxicity of hexazinone in selected organisms and detected maximum levels in foliage, twigs and leaf litter from boreal mixedwood 160

8-1 Total nutrient concentrations (g/kg) in the LFH of the control, 2 and 4 kg ai/ha treatment plots, Block 2 for 1986, 1987, and 1988 (mean ± 95% confidence limits) 168

8-2 Extractable concentrations (mg/kg) in the LFH of the control 2 and 4 kg ai/ha treatment plots, Block 2 for 1986 and 1987 (mean ± 95% confidence limits) 170

FIGURES

4-1 Location of cutblock test areas 4004 and 4007 5

4-2 Vegetation in the Grande Prairie study area before application of treatments. 6

4-3 Schematic layout of blocks and treatment plots, Forest Vegetation Management R&D Project, Canada-Ablerta Agreement, Grande Prairie. 7

4-4 Differenet treatments to achieve vegetation control 9

4-5 Example of sample plots and subplots within treatment plots, Method II, Block 1 .. 10

4-6 Environment Components Monitored 12

4-7 Pretreatment soil surface disturbance and vegetation damage 30

4-8 Symptoms of hexazinone damage (applied as PRONONE 10G at 4kg/ha rate) 32

4-9 Effects of 4 kg hexazinone/ha (as PRONONE™ 10G) on plant species 33

4-10 Percentage change in density of live woody stems over 50 cm high 39

4-11 Percentage change in density of live aspen stems over 50 cm high 40

4-12 Percent frequency of cover classes (1986-1989) for tall shrub foliage in control and hexazinone-treated (as Pronone 10G) plots 56

4-13 Percent frequency of cover classes (1986-1989) for medium shrub foliage in control and hexazinone-treated (as PRONONE 10G) plots 57

4-14 Percent frequency of cover classes (1986-1989) for forb and low shrub foliage in control and hexazinone-treated (as PRONONE 10G) plots 58

4-15 Percent frequency of cover classes (1986-1989) for graminoids in control and hexazinone-treated (as PRONONE 10G) plots 59

4-16 Percent frequency of cover classes (1986-1989) for mosses in control and hexazinone-treated (as PRONONE 10G) plots 72

4-17 Vegetation trajectories in Blocks 1 and 2 of the operational application. Letters refer to treatment (C = 0 kg/ha; L - 2 kg/ha; H = 4 kg/ha). Numbers refer to the year of observation (6 = pretreatment data from 1986; 7 = 1987; 8 = 1988; 9 = 1989). Eigenvalues reflect the amount of vegetation variation explained by successive DCA axes (only axes 1 and 2 graphed) 76

4-18 General conditions of the vegetation in site-treatment plots 79

4-19 General conditions of the vegetation in site-treatment plots 80

5-1 Weight distribution of granules with blank protective coating from a 10-kg lot (n = 315) 85

5-2 Distance deposition rates and distribution profile of granules from the ground application using Ace Rotary Pellet Applicator at 40 kg/ha application on flat ground (A) and with an artificial bump (C), 20 kg/ha on flat ground (B) and with bump (D). SW = designated swath width (5 m) 86

5-3 Distance deposition rates and distribution profile of granules from the aerial applicaiton using helicopter-Isolair Applicator-Spreader at 20 kg/ha (A) and 40 kg/ha (B) application. R = right-hand side of the swath, L = left-hand side of the swath 89

5-4 Mean hexazinone deposition of four plots collected between 5 and 50 m in each plot after application with a backpack logarithmic sprayer 97

5-5 Dissipation of hexazinone in northern Alberta soils. Experiments were initiated on 18 September 1986 at Calling Lake Ranger District. Mean residue values of hexazinone (four replicates) were obtained by means of two sampling methods: a glass jar method (o) for the surface soils at zero-time and a corer method (■) for the 0-30 cm soil layer in the subsequent samplings, and presented with linear regression equation (----) 104

5-6 Flow chart of the microcolumn method for determination of hexazinone and metabolites A and B in soils 109

5-7 Flow chart of the microcolumn method for determination of hexazinone and metabolites A and B in vegetation samples 111

6-1 Schematic illustrating the simulated rainfall apparatus for testing the release of surface coated hexazinone (ai) from the PRONONE 10G granular formulation: (G) granules; (F) filter paper; (TS) Tyler No. 60 sieve; (C) clamps; (BS) buret stand 115

6-2 Cross Section (1a) and Front View (1b) of Soil Leachates Collector GT: Grouting; PVC: PVC Pipe, 60 × 5 cm Perforated with 1-cm Opening at 7-cm Spacing; WB; 500-mL Narrow Mouth Plastic Water Bottle 126

6-3 Hexazinone concentration (2a), volume of soil leachates (2b) and total weight of hexazinone residues (2c) in soil leachates collected at different depths from the 4 kg ai/ha treated plot between 227 and 448 days after PRONONE 10G treatment 129

6-4 Hexazinone concentration 3a), volume of soil leachates (3b) and total weight of hexazinone residues (3c) in soil leachates collected at different depths from the 2 kg ai/ha treated plot between 227 and 448 days after PRONONE 10G treatment 131

Section 2

INTRODUCTION

A sustained supply of timber is an important element in the long-term economic health of the western and the northern regions and of Canada as a whole. Alberta has a well-developed softwood industry and must support and promote softwood reforestation aimed at maintaining the the coniferous forest of lodgepole pine (*Pinus contorta* Dougl.) and white spruce (*Picea glauca* (μg/g) (Moench) Voss.). Recently, Kuhnke (1989) summarized the silviculture statistics (1975-86) of Canada, including Alberta.

Site preparation and control of competing vegetation are critical on thousands of hectares of productive softwood sites in Alberta that are either inadequately stocked or have regenerated to less valued hardwoods. Aspen brush and grasses can be serious problems in some of the recent cutovers designated for softwood regeneration in mixedwood areas and in aspen stands that have been converted to softwoods. The problems exist both at stand establishment and later at stand-tending stages for conifer release to free-to-grow state. Unless silviculturally effective and environmentally acceptable methods of vegetation control are developed, the risk to future and past investments in reforestation are real and will increase in the future.

At present herbicides as well as nonchemical methods of vegetation control (such as site scarification, prescribed burning, mechanical and manual release treatments) provide a wide range of options for forest vegetation management. However, information is needed on the comparative effectiveness of these methods, their economics and environmental impacts specific to sites and to target and crop species. In 1985 there was a particular lack of information on the residue chemistry and environmental impact of forestry herbicides (glyphosate, hexazinone, and triclopyr) and their metabolites under the Alberta climatic conditions.

A fundamental part of any environmental impact study is the measurement of the stress agents, which in this case included manual, mechanical, and chemical methods. Such an investigation requires large numbers of samples for assessing growth of the crop species, target and nontarget species, and properties of soils and leaf litter as well as for determining the herbicide distribution, persistence, and movement in air, soil, soil leachate, and water and the uptake and degradation in vegetation and wildlife. The forest vegetation management project was undertaken within the Canada-Alberta Forest Resource Development Agreement (FRDA), under Project Activity B, subprogram B.3 (Forestry Research, Development & Demonstration). The program was a joint undertaking by Forestry Canada, Northwest Region, Northern Forestry Centre and the Alberta Forest Service Research Branch and Reclamation Branch, with shared roles in planning, management, and implementation with other cooperators.

The project was started in the fall of 1985 with expected termination in 1989-90. This report presents the information available to date on the Environmental Impact Assessment Component of the selected methods of site preparation and crop release in an area designated for softwood production in Alberta.

Section 3

OBJECTIVES

FRDA subprogram B.3 supported research into three areas of forest vegetation management: 1) silviculture, 2) environmental impact of herbicides used in forest vegetation management, and 3) economic assessment. Though the environmental impact assessment project included chemical as well as mechanical and manual methods of vegetation management, the environmental component was designed with a particular emphasis on the environmental impacts and residue chemistry of a specific herbicide, hexazinone[1] (as PRONONE 10G[2] and Velpar L[3] formulations), which had a potential for registration for forestry use in Canada. The objectives of the environmental component of the project were:

1) Develop an environmental impact and residue data base on forestry herbicides with potential for operational use in managing vegetation in Alberta.

2) Determine the fate of herbicides in the forest ecosystem by studying herbicide deposition; active ingredient (ai) release; persistence of herbicides in soil, foliage, and water; lateral and downward movement; degradation; and absorption-desorption characteristics in selected forest soils under field and laboratory conditions.

3) Evaluate the influence of herbicide application and other silvicultural practices on the structure, composition, and dynamics of forest plant communities.

4) Determine the influence of herbicide application and other silvicultural practices on the long-term stability of nutrient balance and the biological (mycorrhizal associates, N-fixation, decomposition) control of tree nutrition.

The major emphasis todate has been to complete pre- (1986) and posttreatment (1987-89) sampling of vegetation, soil and soil leachates, surface water, and sediments to assess 1) changes in plant species and communities as a result of treatments; 2) herbicide PRONONE 10G (a granular hexazinone formulation) distribution and deposition from aerial and ground application (including technology for application, sampling and residue analysis), hexazinone release from the formulation and its movement in soil, and persistence of hexazinone and its metabolites in various forest substrates; 3) hexazinone effects on mycorrhizae; and 4) hexazinone effects on nutrient cycling and dynamics.

Significant impacts of forest vegetation management, particularly when herbicides and complete removal of vegetation by mechanical means are involved, on fish and wildlife are possible. In this

---

[1] Hexazinone: Registered trade mark of E.I. DuPont de Nemours and Co., Wilmington, DE 19898. Active ingredient in the formulation PRONONE 10G is hexazinone.

[2] PRONONE 10G: Registered trademark of Pro-Serve Inc., 400 E. Brooks Rd., Memphis, TN 38116. a granular formulation surface-coated with 10% hexazinone (ai, w/w),

[3] Velpar L: Registered trade mark of E.I. DuPont de Nemours and Co., Wilmington, DE 19898. Liquid formulation of hexazinone.

project impacts on fish were excluded by locating the study plots away from fish- bearing or other water bodies. Impacts on wildlife, particularly on ungulates, were limited to assessing herbicide residues in ungulate browse and changes in forage species. Impact of the herbicide PRONONE 10G on small mammal population was studied under a separate contract and is reported by Penner and Associates (Penner 1990).

Section 4

VEGETATION CHANGES AND ENVIRONMENTAL IMPLICATIONS

4.1 STUDY AREA

The Grande Prairie study area was located on two cutblocks, 4004 and 4007, within the Proctor and Gamble Forest Management Agreement Area, about 21 km south of the Grande Prairie pulp mill. The area is located in Township 68, Range 6, west of the 6th meridian in Improvement District 16 (NTS Big Mountain Creek sheet, Fig. 4-1). The site is within the mixedwood forest complex of Alberta.

Cutblocks 4004 and 4007 were logged in March and July 1983 respectively. Prior to logging, the site supported an 80% *Populus tremuloides* (Aspen) dominated forest with a 20% admixture of *Picea glauca* and *Pinus contorta*. Cutblock 4004 consisted mainly of 19-25 m high aspen with 71-100% crown closure (Fig. 4-2). The aspen was 50-65 years old. After logging, aspen resprouted and predominated through much of the study area.

The study area lies within the mixedwood section of the boreal forest region (Rowe 1972) on the Alberta plateau (Bostack 1970). Before harvest, the vegetation belonged to the *Populus tremuloides* facies of the *Picea glauca-Viburnum edule-Aralia nudicaulis* ecosystem described by Corns and Annas (1986). After logging, aspen saplings (1-2 m tall) formed an almost continuous canopy (Fig. 4-2). Saplings were shorter and their canopy more open in seasonally wet areas. Small numbers of *Amelanchier alnifolia, Alnus crispa*, and *Salix* spp. were intermixed with *P. tremuloides*. Herbaceous vegetation was dominated by *Aster conspicuus, A. ciliolatus, Epilobium angustifoluim, Aralia nudicaulis*, and *Cornus canadensis*. Low shrubs included *Rosa acicularis, Symphoricarpos albu*, and *Spiraea betulifolia*. Seasonally wet local areas had a greater abundance of *Oryzopsis asperifolia, Vaccinium caespitosum*, and *Fragaria virginiana* along with the mesophytic species listed above (Fig. 4-2). The study area is a moderately sloping to nearly level (0-15% slope) glacio-lecustrine plain approximately 850 m above sea level. The parent material is fine-textured clay and has a very low permeability. Surficial deposits in cutblock 4004 consist mainly of an undulating lacustro-till blanket, while cutblock 4007 is characterized by an undulating to moderately rolling lacustro-till blanket. The lacustro-till is characterised by clay to heavy-textured clay that is stone-free to slightly stony.

The soils in both cutblocks consist primarily of gleyed solonetzic grey luvisols. Both orthic luvic gleysols and humic luvic gleysols have developed in poorly drained, level to depressional areas. The study area was surveyed in detail by Pedology Consultants; and details of soil descriptions, drainage and parent materials for each treatment plot are summarized in their report (Twardy and Dowgray 1985).

4.2 PLOT LAYOUT AND EXPERIMENTAL DESIGN

The Grande Prairie study covered two major aspects of vegetation management: site preparation and conifer crop release. The conifer release experiment was set up on cutblock 4004, referred to as Method I; and the site preparation experiment was set up on cutblock 4007, referred to as Method II. For each method, the plots within blocks were laid out in a nonrandomized complete block design with three replicate blocks (Fig. 4-3). Treatments were randomly arranged within one block and the arrangement was repeated for the other two blocks to minimize the confounding consequences of the aerial application of herbicide and to facilitate the operations of

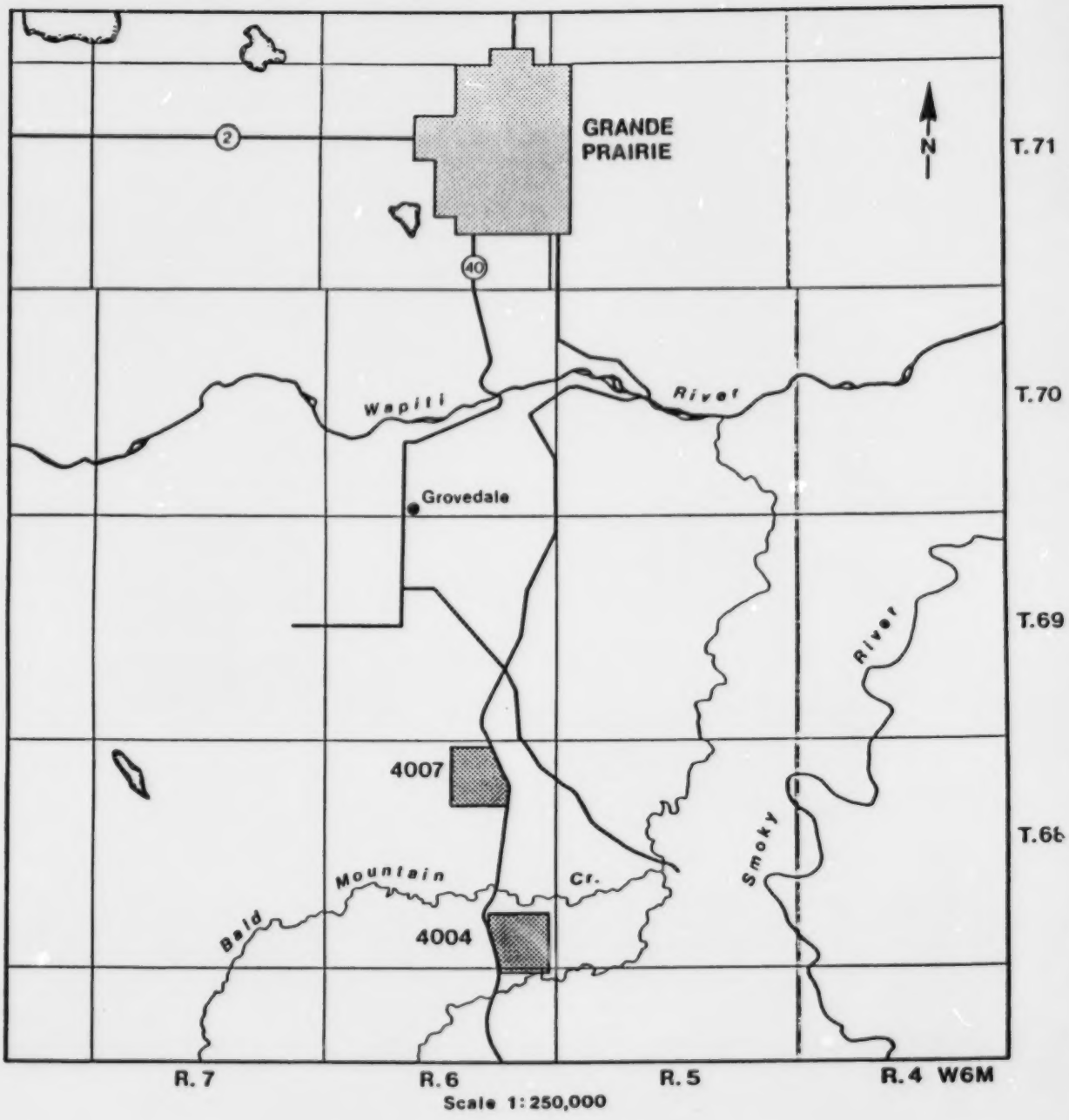

Figure 4-1. Location of cutblock test areas 4004 and 4007.

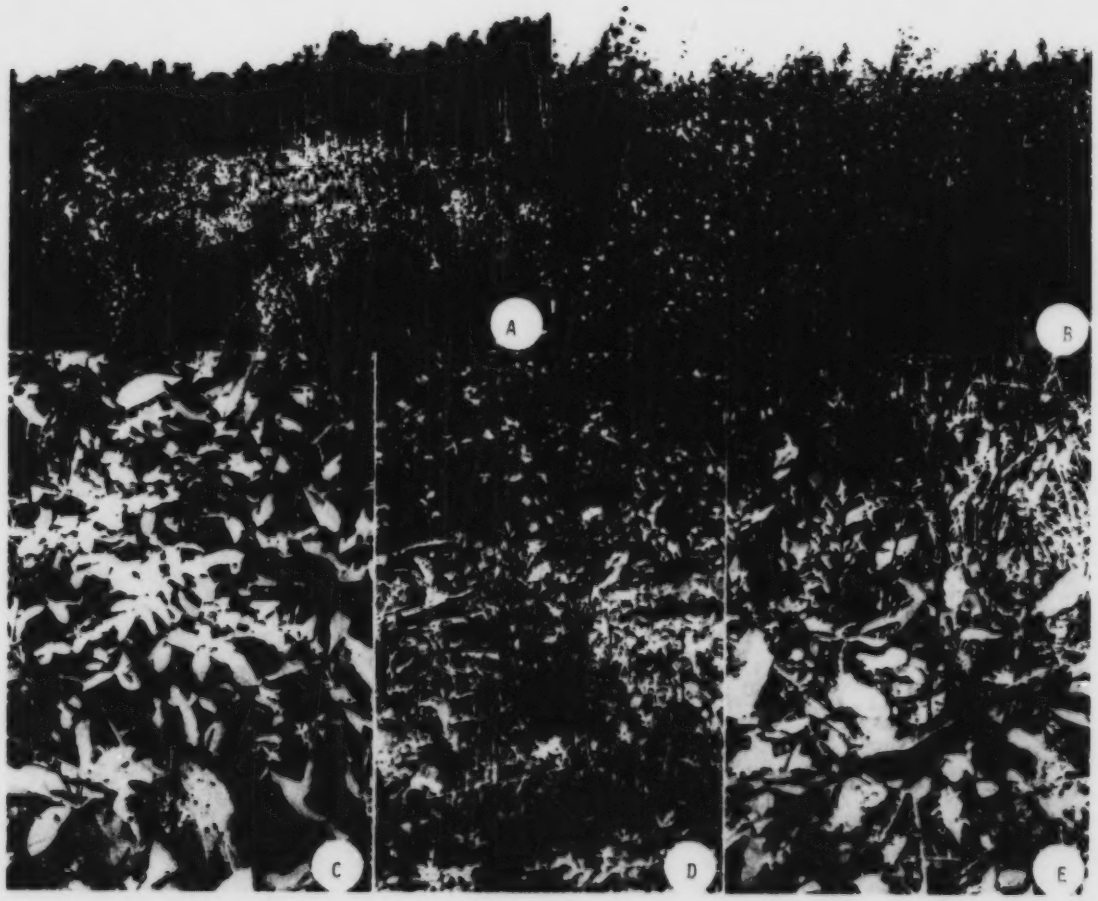

Figure 4-2. Vegetation in the Grande Prairie study area before application of treatments. A. General view of the vegetation dominated by Populus tremuloides (aspen) with admixture of Pinus contorta. B. Vegetation following harvest dominated by aspen and Calamagrostis canadensis C. Closeup of other understory herbaceous and woody species (Aster conspicuus, A. ciliolatus, Lonicera involucrata). D. Invading species such as Taraxacum officinale, Trifolium repens, Bromus inermis on scraped-off areas. E. Closeup of forb layer dominated by Epilobium angustifolium, Galium boreale, Castilleja miniata and Amelanchier alnifolia in foreground.

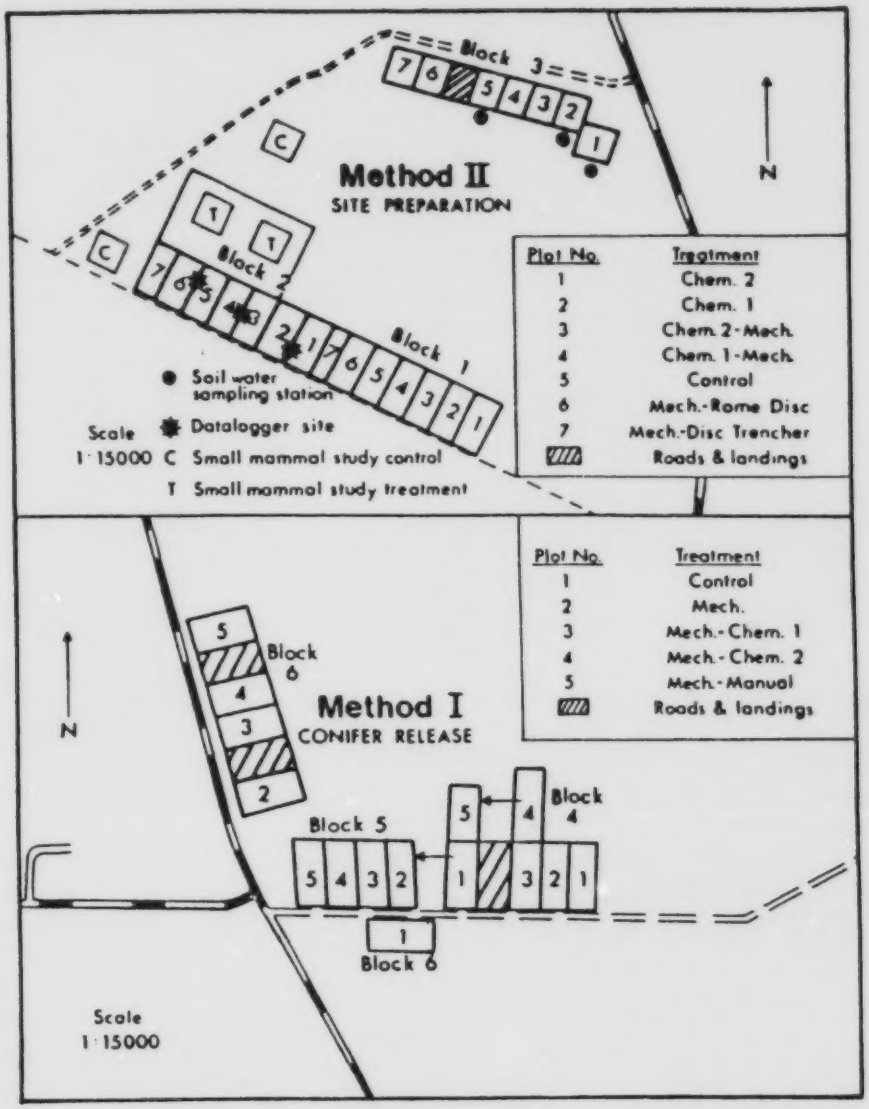

Figure 4-3 Schematic layout of blocks and treatment plots, Forest Vegetation Management R&D Project, Canada-Ablerta Agreement, Grande Prairie.

heavy machinery for mechanical treatments. The different treatments and the time of application for each method are listed below and illustrated in Figure 4-4.

I. Conifer Release (Method I)

	Treatment (Abbreviation)	Time of application
1.	Control (C)	No treatment
2.	Mechanical - Rome Double Disk (DD)	12-15 May 1987
3.	Mechanical - Disk Trencher followed by PRONONE 10G at 2 kg ai/ha (DT + LH)	DT on 12-15 May 1987, PRONONE Applied 30 May 1989
4.	Mechanical - Disk Trencher followed by PRONONE 10G at 4 kg ai/ha (DT + HH)	DT on 12-15 May 1987 PRONONE applied 30 May 1989
5.	Mechanical - Disk Trencher followed by manual release by brushsaw (DT + BS)	DT on 12-15 May 1987 followed by manual brushsaw mid May to mid June 1989

II. Site Preparation (Method II)

	Treatment	Time of Application
1.	Control	No treatment
2.	PRONONE 10G at 4 kg ai/ha (chemical 2 in Fig. 4-3, HH)	28 August 1986
3.	PRONONE 10G at 2 kg ai/ha (chemical 1 in Fig. 4-3, HH)	28 August 1986
4.	PRONONE 10G at 4 kg ai/ha followed by mechanical - Disk Trencher (HH + DT)	PRONONE applied 28 August 1986 followed by mechanical on 12-15 May 1987
5.	PRONONE 10G at 2 kg ai/ha followed by mechanical - Disk Trencher (LH + DT)	PRONONE appled 28 August 1986 followed by mechanical on 12-15 May 1987
6.	Mechanical - Rome Double Disk (DD)	13-18 May 1987

Both white spruce and lodgepole pine planting stock was produced by the Alberta Forest Service as plug +1 spruce and container-grown lodgepole pine. Plantings were done following mechanical treatments in May 1987 on both Method I and Method II areas. Each treatment plot was approximately 80 m × 180 m. A central portion of each treatment plot (30 m × 150 m) was reserved for establishing permanent plots for sampling vegetation. Typical treatment and sample plots for Method II are shown in Figure 4-5. Three rows of ten 5 m × 5 m squares, regularly distributed, were permanent subplots set up in each sample plot for vegetation sampling. No destructive sampling was allowed within these subplots. Foliage and soil samples were collected from two corridors on either side of the central row of subplots. In addition, leaf litter, soil leachates, and soil samples were collected for nutrient and residue analyses outside the vegetation sampling subplots and quadrats

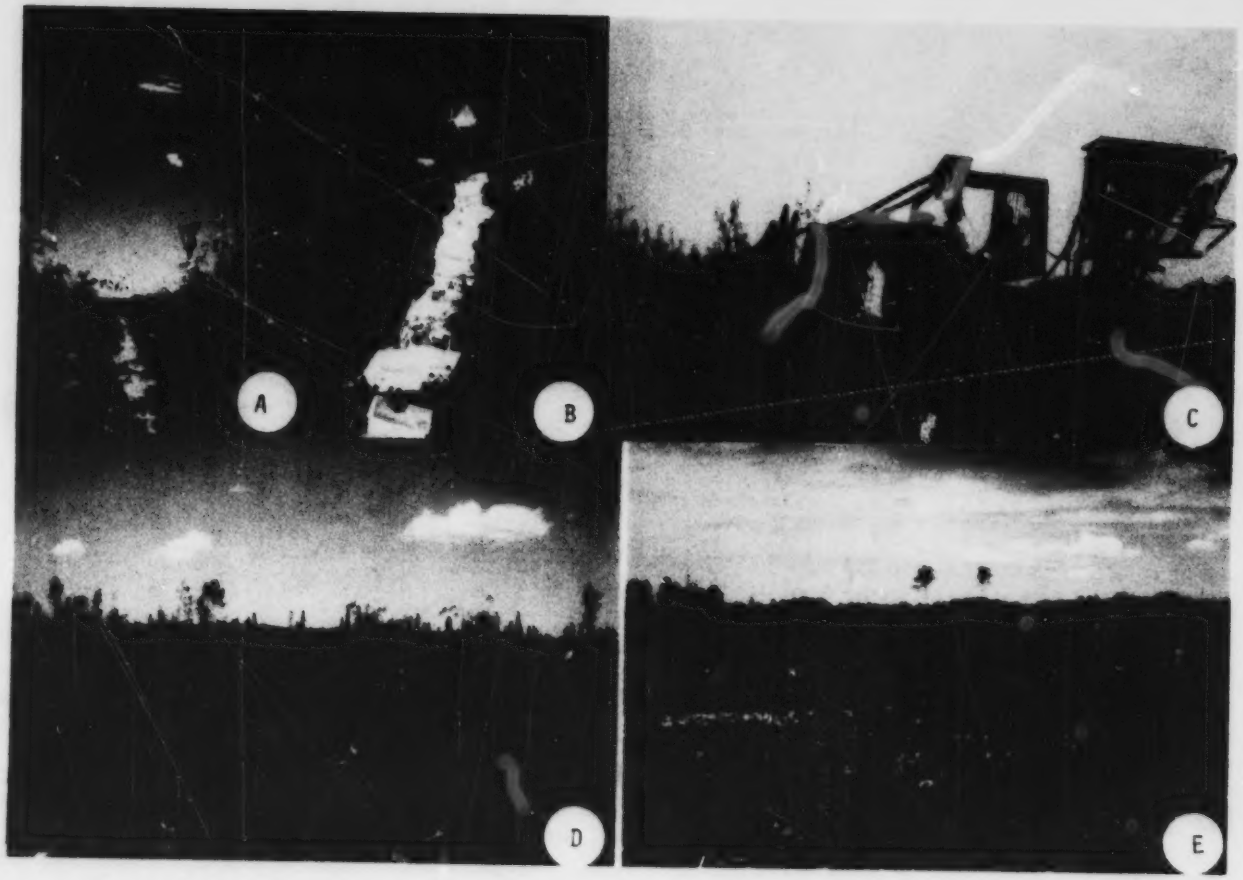

Figure 4-4. Different treatments to achieve vegetation control. A. Aerial application of herbicide PRONONE 10G with Isolair Applicator-Spreader attached to a helicopter. Site preparation plots were aerially treated in fall, 1986. **B.** Collection trays on both ends of herbicide treatment plots were used to evaluate the distribution and deposition rate of the herbicide. **C.** Granule - Air Applicator used to treat the crop release plots in 1989. **D.** Disk-trenching treatment. Single run of a disk-trencher resulted in approximately 1 m wide undisturbed swath in center, 2 disk-trenches on either side and burms of excavated and overturned material on the edges. **E.** Double-disked plots with complete removal of vegetation cover and exposure of a variety of surface and deep soil horizons.

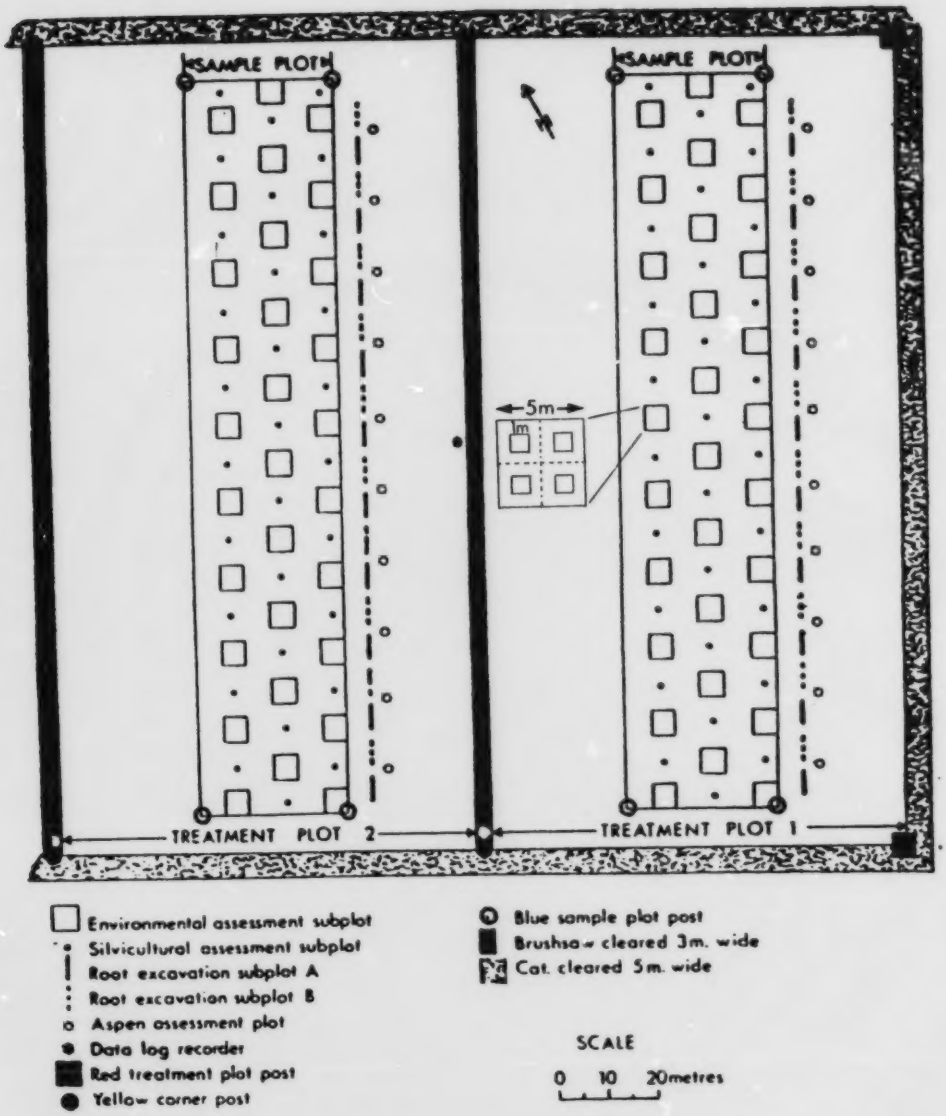

Figure 4-5. Example of sample plots and subplots within treatment plots, Method II, Block 1.

(Fig. 4-6 and Sections 6 and 8). Each 5 m × 5 m subplot was further divided into four quadrants and a 1 m × 1 m quadrat was permanently established in each quadrant of the herbicide-only and control plots (Fig. 4-5). There were 120 quadrats in each relevent treatment plot for Method II (site preparation) and 80 quadrats in each treatment plot for Method I (crop release).

4.3 VEGETATION SAMPLING AND ANALYSIS OF DATA

The vegetation sampling was designed to document pretreatment status of vegetation (including insect and disease damage to foliage) and to detect changes in vegetation in response to various vegetation management treatments in terms of species occurrence, live stem density of woody species, and percent cover of all species. Different vegetation strata were monitored in order to document changes in vegetation composition and identify successional trends. The vegetation was sampled yearly from 1985 to 1989.

4.3.1 Symptomology and Evaluation of Herbicide and Insect-Disease Damage

4.3.1.1 The herbicide

A new granular formulation (PRONONE 10G) of the herbicide hexazinone was selected for the study. Hexazinone provides both contact and residual control of several plant species. The formulation is registered for forestry in Canada (woodland management areas, Registration No. 2/390) and the USA (EPA Reg. No. 33560-21). Chemically, the ai is known as 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5,-triazine-2,4(1H,3H)-dione (C_{12} H_{20} N_4 O_2; C = 57%, H = 7.9%, N = 22.2%, and O = 12.7%). It has full registration and the product is certified to be free of contaminants like dioxin and PCBs. The herbicide is available in three formulations: liquid Velpar L, granular PRONONE 10G, and wettable powder Velpar K. Each formulation must be registered separately for its respective use in Canada. At present, Velpar L and PRONONE 10G have full registration for forestry use by ground application. As of December 1990, Velpar L label was ammended by Agriculture Canada for its aerial application for conifer site preparation. When the present study was undertaken, the formulation PRONONE 10G was not registered, and the Grande Prairie research was carried out under a specific experimental label issued by Agriculture Canada and Alberta Environment to gather information on the efficacy, crop tolerance, effects on nontarget species, herbicide residue in soils and plants, off-site movement of herbicide, effects on wildlife browse, effects on small mammals, and residues in surface and groundwater. The information described in this report is relevent to the boreal forest region and specifically for conditions on the Grande Prairie site in Alberta.

The PRONONE 10G formulation was selected for the following reasons:

1) Aerial or ground application of the PRONONE 10G will result in minimal off-site drift because of the large size (2-5 mm) and weight (20 mg average) of its granules.
2) Operators will have very little direct contact with the a.i. hexazinone during handling and application because each granule is coated with an inert protective coating.
3) Activity of the formulation is not dependent on its direct contact with foliage. Hexazinone is readily released from the dry granules when exposed to sufficient moisture and becomes easily available to the roots.

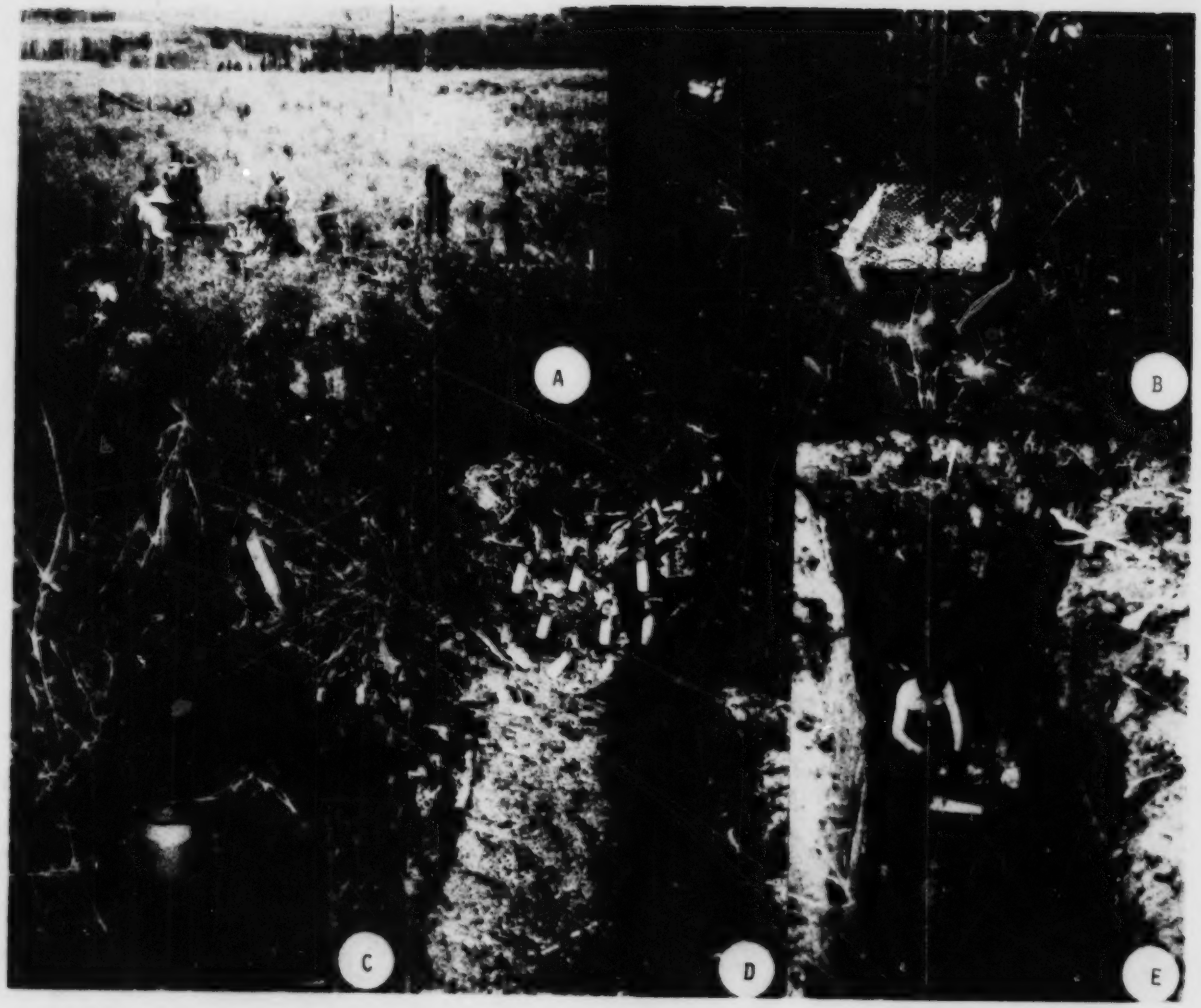

Figure 4-6. Environment Components Monitored. **A.** Permanent vegetation subplots (5m x 5m), metal rod in the centre and wooden stakes mark the 4 quadrants for stem density counts. **B.** Litterfall trap made out of nylon mesh. **C.** Collection bottle attached to zero-tension lysimeter buried under the LFH horizon. **D.** Bottles collecting soil-leachate draining from horizontal wells at 30, 55, and 80 cm depths. **E.** Collection of soil samples to a depth of over 2 m for hexazinone residue analysis.

4) It controls a broad spectrum of woody, herbaceous and graminaceous plant species.

5) It stays active in soil for at least two growing seasons so should provide both immediate and residual control.

In the present study, PRONONE 10G was applied aerially at nominal rates of 2 and 4 kg hexazinone/ha (see Section 5 for deposition and distribution) to site-preparation plots on 26 August 1986 and by a tractor-mounted ground applicator to crop release plots on 28-29 May 1989 (Section 5.1).

4.3.1.2 Mode of action

Hexazinone can be absorbed through foliage as well as roots. The primary pathway depends on the formulations used: when applied in a liquid form, both foliage and root mediated absorption takes place, and when applied in granular form practically all absorption takes place through the roots (Ghassemi et al. 1982; WSSA 1983). In the case of PRONONE formulation, once the hexazinone is released from the granules it is absorbed by the roots and translocated to stems and leaves with the water stream. The mechanism by which plants are affected and the relative sensitivity of plant species are not completely known. But there is evidence that it can interfere with photosynthesis and with RNA and lipid synthesis. Of these metabolic processes, photosynthesis is reported to be the first and most sensitive process inhibited by hexazinone and other S-triazine herbicides (Hatzios and Howe 1982). Hexazinone is primarily translocated through apoplasts to the site of action in the mesophyll (Beste 1983; McNeil, Stritzke and Basler 1984) and interferes with the photosynthetic reduction of CO_2 in the dark (WSSA 1983).

Hexazinone blocks the photosynthetic process and eventually causes visible necrosis of the susceptible tissues. It appears that dimethylamino or methylamino groups and nonsubstituted 3-cyclohexyl rings are critical to blocking of the photosynthesis. The parent compound, hexazinone, breaks down into two major (A and B) and six minor (C, D, E, F, G, and H) metabolites. The parent compound is most effective; however, metabolite B is also phytotoxic. The weaker activity of metabolite B appears to be related to demethylation of the 6-dimethylamino group during its formation (Sung et al. 1985).

The degree of damage to a species depends on its sensitivity, rate of application and uptake, and physical environmental factors. The tolerance of plant species to S-triazine herbicides can be attributed to reduced uptakes or translocation, or degradation of the absorbed herbicide to inactive compounds (Freeman, White and Bukovac 1964; Sikka and Davis 1968). Hexazinone behavior in tolerant species appears to follow a similar pattern. Tolerance of pine and eastern red cedar to hexazinone has been attributed to rapid degradation and to low amounts of hexazinone translocated to foliage, respectively. In sugar cane, however, the tolerance is probably due to both low uptake and degradation of the absorbed herbicide to inactive compounds (Reiser, Belasco and Rhodes 1983).

There is very little information available on the mass balance of hexazinone applied to a forest system. How much of the applied herbicide is absorbed, translocated, and maintained as residues in plants? How much is metabolized in soil? What proportion is leached to various depths and moved to groundwater level? The present study provides some data on off-site drift and concentration of hexazinone and its metabolites in surface water, soil leachate, soil, and plants. Baron and Monaco (1986) studied the comparative uptake, translocation, and metabolism of hexazinone in blueberry and

hollow goldenrod. The authors reported that blueberry plants absorbed on the average 7.9% of the root-applied hexazinone compared with 10.1% by goldenrod. An average of 6.8% of the root-absorbed hexazinone was translocated from roots to the stem and leaves in blueberry while this percentage was as high as 50% in goldenrod. The lower sensitivity of blueberries to hexazinone was attributed to the restricted translocation of the absorbed herbicide to stems and leaves.

4.3.1.3 Methods of assessing herbicide damage

Vegetation in the Grande Prairie plots was monitored intensively for visual hexazinone damage symptoms, survival of woody stems (density of live stems), and changes in vegetation cover for a year before and for each of 3 years, posttreatment growing seasons.

Two methods were used to understand the effects of the herbicide on phenological development and loss of the most common photosynthetic tissue in the most common species occurring in the study plots.

a) **Detailed phenological development of selected species**

The observations were restricted to the control and herbicide-treated plots. The 1 m × 1 m quadrats located in each of the five randomly selected 5 m × 5 m subplots in control, high herbicide, and low herbicide treatment plots (Fig. 4-5) were visited at 2-week intervals from May to the end of August 1987 (the growing season following the herbicide application on 26 August 1986). The vegetation phenologies, insect and disease damage, and herbicide damage were monitored for each species present. Numerical ratings were applied as follows:

0 - no leaf tissue present
2 - green leaves visible but often folded as in bud
3 - leaves partially expanded
4 - leaves fully expanded but soft light green or red
5 - leaves mature with normal colors and texture
7 - shoots dead, leaves lost
9 - leaves senscing
10 - 20-80% insect damage
11 - 20-80% herbicide damage
13 - > 80% herbicide damage

b) **Rated damage due to herbicides, insects, and diseases**

Twenty points were sampled, ten in each of the two corridors between three rows of 5 m × 5 m plots (Fig. 4-5). At each point the closest and the tallest stem of each woody species, or a clump in case of grasses, was observed for insect-disease or herbicide damage, and visual estimates of the intensity of damage to the foliage were assessed and recorded. Based on the extent of foliar damage, the sample was classified in one of the following damage classes.

Damage Rating Class	Description
I	0 to 5% of the foliage surface affected by insect ordisease, no clear symptoms of herbicides discernible, foliage green and healthy
II	5 to <25% of foliage damaged by herbicide (chlorotic, necrotic, deformed, cupped leaves) or by insect and disease
III	25 to <50% showing damage by herbicide, insect or disease
IV	50 to <75% with herbicide, insect or disease damage
V	>75% foliage damaged by herbicide, insect or disease

In 1987 the herbicide-treated and control plots were monitored for foliar herbicide damage in May, June, July, August, and September for 21 leading species (Table 4-1) to establish the pattern of development of herbicide damage on foliage of a large number of species. For 1988 and 1989 monitoring, the sampling was limited to five or six of the most important woody, herbaceous, and graminoid species (Tables 4-2, 4-3).

During 1986 (pretreatment sampling of plots) aspen was observed to have been infested with ink spot (*Cibornia whetzellii* (Seaver)). A damage survey of the vegetation in all treatment plots of Blocks 1 to 3 was carried out in June 1986 (Table 4-4). Fifty stems were sampled from each treatment plot and the top 20-cm section of each stem was observed for occurrence of ink spot, percentage of leaves affected, and estimated foliar surface damaged. The data were collected for future reference when evaluating the impact of herbicides and other vegetation management techniques.

4.3.2 Stem Density

Pretreatment stem counts of all woody stems 50 cm or over in length were included in counts. Stems in three height classes (A = 50-150 cm, B = 150-500 cm, C = > 500 cm) were counted by species. Thirty 5 m × 5 m subplots were sampled in 1985-86, 1987, and 1988 in all Method II (site preparation) treatment plots and 20 subplots in Method I (crop release) plots. The intensity of sampling was 50% in 1989 in Method II plots, except high-herbicide-plus-mechanical and low-herbicide-plus-mechanical plots of Blocks 1 and 2 which were not sampled in 1989 (Table 4-6). No stem counts were done in 1989 on Method I plots because of application of the chemical and mechanical crop release treatments in 1989. These plots are due for sampling in 1990-91 for treatment effects.

4.3.2.1 Analysis of stem density data

The density data from treatment plots of Method II only were analyzed and summarized for the purpose of this report. Method I is due to be sampled in 1991-92 for total effects of mechanical and chemical treatments. Density data from 30 subplots were summarized as means and coefficient of variance for each treatment plot. The averages were presented as number of stems per hectare. The

Table 4-1. Percent (n = 60) stems (top 20 cm) in each foliar damage class in herbicide-treated and control plots at various times during 1987. Plots were treated on 28 August, 1986.

Species	Dam.** class	Treatments** 26-28 May			25-26 June			21-22 July			18-19 August			3-4 September		
		C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH
Prunus tremuloides	I	100 (30-I/D)	93 (10-I/D)	66 (13-I/D)	100 (30-I/D)	48 (6-I/D)	18	100	48 (6-Regen)	22	100	72 (50-Regen)	12	100	52 (45-Regen)	18
	II	-	7	27	-	18	13	-	28	27	-	10	5	-	7	10
	III	-	-	7	-	10	10	-	5	17	-	10	-			-
	IV	-	-	-	-	2	16	-	5	17	-	3	30	-	10	4
	V	-	-	-	-	22	43	-	14	17	-	15	53	-	23	58
Aster conspicuus	I	100	42	37	100 (10-I/D)	27	17	100	32	5	100	50 (20-Regen)	45 (45-Regen)	100	100 (70-Regen)	100 (100-Regen)
	II	-	58	60	-	58	18	-	18	22	-	32	30	-	-	-
	III	-	-	3	-	15	10	-	13	16	-	6	8	-	-	-
	IV	-	-	-	-	-	15	-	15	25	-	2	8	-	-	-
	V	-	-	-	-	-	40	-	22	32	-	10	9	-	-	-
Calamagrostis canadensis	I	100	33	23	100	13	7	100	-	-	100	12 (12-Regen)	-	100	22	-
	II	-	7	-	-	-	-	-	-	-	-	-	-	-	10	-
	III	-	33	77	-	17	-	-	-	-	-	8	-	-	8	-
	IV	-	10	-	-	-	3	-	3	-	-	3	-	-	-	-
	V	-	17	-	-	70	90	-	97	-	-	82	100	-	60	100
Amelanchier alnifolia	I	100	95	70	100	60	40	100	33	13	100	22	10	100	25	15 (Regen)
	II	-	5	30	-	40	40	-	37	48	-	43	15	-	35	25
	III	-	-	-	20	-	-	-	17	24	-	-	10	-	-	-
	IV	-	-	-	-	-	-	-	3	13	-	5	15	-	-	3
	V	-	-	-	-	-	-	-	10	20	-	30	50	-	40	60

Table 4-1 (Continued). Percent (n = 60) stems (top 20 cm) in each foliar damage class at various times in herbicide-treated and control plots during 1987. Plots were treated on 28 August, 1986

Species	Dam.** class	Treatments** 26-28 May			25-26 June			21-22 July			18-19 August			3-4 September		
		C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH
Salix spp.	I	100	86	43	-	-	-	100	63	40	-	-	-	100	80 (20 Regen)	70 (50 Regen)
	II	-	14	57	-	-	-	-	27	7	-	-	-	-	20	7
	III	-	-	-	-	-	-	-	-	10	-	-	-	-	-	10
	IV	-	-	-	-	-	-	-	-	13	-	-	-	-	-	13
	V	-	-	-	-	-	-	-	-	30	-	-	-	-	-	-
Rosa acicularis	I	100	90	43	100	20	-	100	21	10	100	65	23	100	40 (Regen)	38 (Regen)
	II	-	10	47	-	40	-	-	25	26	-	10	18	-	35	30
	III	-	-	10	-	40	30	-	20	20	-	25	37	15	-	-
	IV	-	-	-	-	-	30	-	17	9	-	-	7	-	17	20
	V	-	-	-	-	-	40	-	17	35	-	-	15	-	8	7
Shepherdia canadensis	I	100	100	100	-	-	-	100	80	60	-	-	-	100	80	50
	II	-	-	-	-	-	-	-	20	20	-	-	-	-	20	20
	III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IV	-	-	-	-	-	-	-	-	10	-	-	-	-	-	10
	V	-	-	-	-	-	-	-	-	10	-	-	-	-	-	10

Table 4-1 (Continued). Percent (n = 60) stems (top 20 cm) in each foliar damage class at various times in herbicide-treated and control plots during 1987. Plots were treated on 28 August, 1986

Species	Dam.** class	Treatments** 26-28 May C	26-28 May LH	26-28 May HH	25-26 June C	25-26 June LH	25-26 June HH	21-22 July C	21-22 July LH	21-22 July HH	18-19 August C	18-19 August LH	18-19 August HH	3-4 September C	3-4 September LH	3-4 September HH
	I	100	100	60	100	90	60	100	80	-	100	80	-	100	80	20
	II	-	-	40	-	10	30	-	10	-	-	20	70	-	20	-
Viburnum edule	III	-	-	-	-	10	30	-	10	-	-	20	70	-	-	60
	IV	-	-	-	-	-	-	-	-	40	-	-	-	-	-	10
	V	-	-	-	-	-	-	-	-	10	-	-	10	-	-	10
	I	100	100	-	-	-	-	100	75	-	-	-	-	100	70	10
	II	-	-	100	-	-	-	-	25	60	-	-	-	-	30	50
Lonicera involucrata	III	-	-	-	-	-	-	-	-	30	-	-	-	-	40	-
	IV	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	I	100	100	-	-	-	-	100	90	25	-	-	-	100	80	30
	II	-	-	100	-	-	-	-	10	40	-	-	-	100	20	70
Lonicera dioica	III	-	-	-	-	-	-	-	-	25	-	-	-	-	-	-
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4-1 (Continued). Percent (n = 60) stems (top 20 cm) in each foliar damage class at various times in herbicide-treated and control plots during 1987. Plots were treated on 28 August, 1986

Species	Dam.** class	26-28 May			25-26 June			21-22 July			18-19 August			3-4 September		
		C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH
	I	100	100	90	-	-	-	43	53	20	-	-	-	100	74	23 (23-Regen)
	II	-	-	10	-	-	-	7	40	23	-	-	-	-	13	-
Epilobium angustifolium	III	-	-	-	-	-	-	-	-	17	-	-	-	-	-	12
	IV	-	-	-	-	-	-	-	-	13	-	-	-	-	13	48
	V	-	-	-	-	-	-	-	7	27	-	-	-	-	-	17
	I	100	100	100	-	-	-	100	90	-	-	-	-	100	90	-
	II	-	-	-	-	-	-	-	10 (10-Chlorotic)	60	-	-	-	-	10	60
Corylus cornuta	III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	I	-	-	-	100	100	80	100	65	-	100	90	70	-	-	-
	II	-	-	-	-	-	20	-	-	-	-	10	-	-	-	-
Vicia americana	III	-	-	-	-	-	-	-	30	40	-	-	30	-	-	-
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	60	-	-	-	-	-	-

Table 4-1 (Continued). Percent (n = 60) stems (top 20 cm) in each foliar damage class at various times in herbicide-treated and control plots during 1987. Plots were treated on 28 August, 1986

Species	Dam.** class	Treatments** 26-28 May			25-26 June			21-22 July			18-19 August			3-4 September		
		C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH
Aralia nudicaulis	I	100	100	90	-	-	-	100	80	30	100	80	5	-	-	-
	II	-	-	10	-	-	-	-	20	-	-	20 (20-Chlorotic)	20	-	-	-
	III	-	-	-	-	-	-	-	-	40	-	-	20	-	-	-
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	30	-	-	55	-	-	-
Cornus canadensis	I	100	100	100	-	-	-	100	100	100	-	-	-	100	100	100
	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vaccinium myrtilloides	I	100	100	100	-	-	-	100	80	50	-	-	-	100	80	50
	II	-	-	-	-	-	-	-	20	-	-	-	-	-	20	-
	III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IV	-	-	-	-	-	-	-	-	30	-	-	-	-	-	40
	V	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-

Table 4-1 (Continued). Percent (n = 60) stems (top 20 cm) in each foliar damage class at various times in herbicide-treated and control plots during 1987. Plots were treated on 28 August, 1986

Species	Dam.** class	Treatments** 26-28 May			25-26 June			21-22 July			18-19 August			3-4 September		
		C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH	C	LH	HH
Arnica cordifolia	I	100	-	-	-	-	-	100	80	-	-	-	-	-	-	-
	II	-	100	100	-	-	-	-	20	50	-	-	-	-	-	-
	III	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-
	IV	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ribes oxyacanthoides	I	100	90	80	-	-	-	100	80	-	-	-	-	100	80	-
	II	-	10	20	-	-	-	-	20	80	-	-	-	-	20	80
	III	-	-	-	-	-	-	-	-	20	-	-	-	-	-	20
	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lathyrus ochroleucus	I	100	100	90	-	-	-	100	80	20	100	80	20	-	-	-
	II	-	-	10	-	-	-	-	20	50	-	-	50	-	-	-
	III	-	-	-	-	-	-	-	-	20	-	10	20	-	-	-
	IV	-	-	-	-	-	-	-	-	10	-	10	-	-	-	-
	V	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-

*Damage classes: I = 0-5%, II = 5-25%, III = 25-50%, IV = 75-100% of foliar surface damaged or foliage defoliated.
**C = Control, LH = 2 kg hexazinone/ha, HH = 4 kg hexazinone/ha.
***Numbers in parentheses are percent showing I/D, Regen or Dead. I/D = Insect/Disease Damage, Regen = Regrowth from previously defoliated stems, D = Dead stem.

Table 4-2. Percent stems in each foliar damage class in herbicide, mechanical, and control plots on 28 June 1988. Plots were treated on 28 August 1987

Species	Dam. class	Treatments** C	LH	LH + DT	HH	HH + DT	DD
Populus tremuloides	I	100	25	52	23	13	100 (Regen)
	II	-	33	20 (3-1.D)	15 (2-1.D)***	7	-
	III	-	17	7	3	15	-
	IV	-	7	-	5	10	-
	V	-	18 (3D)	21 (3D, 12 Regen)	50 (5D, 5 Regen)	55 (15 Regen, 6D)	-
Aster conspicuus	I	100	100	100	100	100	100
	II	-	-	-	-	-	-
	III	-	-	-	-	-	-
	IV	-	-	-	-	-	-
	V	-	-	-	-	-	-
Epilobium angustifolium	I	100	100	100	100	100	100
	II	-	-	-	-	-	-
	III	-	-	-	-	-	-
	IV	-	-	-	-	-	-
	V	-	-	-	-	-	-
Calamagrostis canadensis	I	100	33	-	12	10	100
	II	-	7	5	8	20	-
	III	-	-	-	3	17	-
	IV	-	7	-	5	-	-
	V	-	53	95	62	53	-
Rosa acicularis	I	100	100	100	-	80	100
	II	-	-	-	100	20	-
	III	-	-	-	-	-	-
	IV	-	-	-	-	-	-
	V	-	-	-	-	-	-
Amelanchier alnifolia	I	100	50	40	10	30	-
	II	-	15	30	20	-	-
	III	-	5	30	-	10	-
	IV	-	-	-	-	40	-
	V	-	30	-	70	20	-

*Damage classes: I = 0-5%, II = 5-25%, III = 25-50%, IV = 75-100%, of folier surface damaged or foliage defoliated.
**C = Control, LH = 2 kg hexazinone/ha, HH = 4 kg hexazinone/ha, DT = Disk trenching, DD = Double disking.
***Numbers in parentheses are percent showing I/D, Regen or Dead. I/D = Insect/Disease Damage, Regen = Regrowth from previously defoliated stems, D = Dead stem.

Table 4-3. Percent stems in each foliar damage class in herbicide and mechanically tested and control plots on 11 July 1969. Plots were treated on 28 August, 1967

Species	Dam. class*	Treatments** C	LH	LH + DT	HH	HH + DT	DD
Populus tremuloides	I	100 (77-1.d)	78 (57-1.D)	77 (57-1.D)	35 (2 Regen)***	50 (33-1.D)	100 (25-1.D, 100
	II	-	10 (3-1.D)	8 (7-1.D)	17 (10-1.D)	5 (3-1.D)	- Regen)
	III	-	-	5 (3-1D)	18 (3-Regen, 12ID)	3	-
	IV	-	-	4	-	2	-
	V	-	12	6 (6-D)	30	40 (37D, 1 Regen)	-
Aster conspicuus	I	100	100	98	78	100	100
	II	-	-	-	10	-	-
	III	-	-	2	3	-	-
	IV	-	-	-	-	-	-
	V	-	-	-	-	-	-
Epilobium angustifolium	I	100	100 with bushy growth)	100	92 (15-multiple stem	80	100
	II	-	-	-	8 (2-1.D)	5	-
	III	-	-	-	-	5	-
	IV	-	-	-	-	-	-
	V	-	-	-	-	-	-
Calamagrostis canadensis	I	100	80 poor growth & eighty chloratic)	60	23 (Plants small)	50	100
	II	-	-	-	27	-	-
	III	-	2 (2-D)	-	3	-	-
	IV	-	-	-	-	-	-
	V	-	-	40 (40-D)	47 (47-D)	50 (50-D)	-
Rosa acicularis	I	100	100	100	84	100	100
	II	-	-	-	-	-	-
	III	-	-	-	-	-	-
	IV	-	-	-	-	-	-
	V	-	-	-	16 (16-D)	-	-

*Damage classes: I = 0-5%, II = 5-25%, III = 25-50%, IV = 75-100% of foliar surface damaged or foliage defoliated.

**C = Control, LH = 2 kg hexazinone/ha, HH = hexazinone/ha, DT = Disk trenching, Dd = Double disking.

***Numbers in parentheses are percent showing I/D, Regen or Dead. I/D = Insect/Disease Damage, Regen = Regrowth from previously defoliated stems, D = Dead stem.

Table 4-4. Frequency and intensity of *Cibornia whetzellii* (Seaver) in various treatment plots and blocks of Vegetation Management (Site Preparation) Study at Grande Prairie, 12 June 1986. Assessments were done prior to any treatment

Blocks	Damage	PL-1	PL-2	PL-3	PL-4	PL-5	PL-6
BL-1	% stems with foliar damage	86	92	96	100	100	100
	% leaves affected on damaged stems	50	74	48	76	100	92
	% damaged leaf surface of affected leaves	16	14	24	11	13	8
	% total leaf area damaged	6.9	9.5	11.0	8.3	13.0	7.4
BL-2	% stems with foliar damage	96	100	100	64	100	100
	% leaves affected on damaged stems	79	67	66	52	24	15
	% damaged leaf surface of affected leaves	41	22	21	23	9	10
	% total leaf area damaged	31.1	14.7	13.9	7.6	2.2	1.5
BL-3	% stems with foliar damage	88	100	90	90	22	10
	% leaves affected on damaged stems	67	48	60	44	6	8
	% damaged leaf surface of affected leaves	7	8	9	15	2	1
	% total leaf area damaged	4.1	3.8	4.9	5.9	20.3	<0.1

[a]100% foliar damage = all leaves, 100% leaf surface, and on all individual stems.

[b]% foliar damage = proportion of stems with foliar damage × proportion of leaves affected × % leaf area damaged; e.g., 0.86 × 0.5 × 16 = 6.9.

Table 4-5. Phenological summary 1987 for aspen (Populus tremuloides) from control and herbicide-treated plots

Treatment	Phenology with Time						
	May	June	July	August	September	October	
	1----------15----------31	1----------15----------30	1----------15----------31	1----------15----------31	1----------15----------30	1----------15----------20	
Control	No leaves	Bud break occurred, leaves partially expanded (Code 3)	Leaves fully expanded, soft, red or light green in color (Code 4)	Leaves mature, normal thickness and texture and lush green. Some clones earlier than others (Code 5)	Leaves begin turning color, senescing and some falling. Some clones later than others (Codes 5, 6)	Stems defoliated but live (Code 6)	
2 kg hexazinone/ha	No leaves	Bud break early in some clones, leaves partially expanded in most, fully expanded in some (Code 3,4)	Leaves fully expanded, soft & light green or red (Code 4,3)	30% of leaves showing varying degrees of herbicide damage. Little or no defoliation. 70% were as in controls. Some completely damaged and folding. (Code 11, 13, 6 in order of frequency)	Terminal regrowth from some stems. most leaves senescing and turning color. (Code 9,5,6)	Leaves senescing and stems defoliated (Code 6, 9). About 15% stems dead (Code 7)	
4 kg hexazinone/ha	No leaves	Bud break delayed, some clones with no leaves (Code 3)	Leaves fully expanded, soft light green, or light red (Code 4)	40% leaves completely damaged (Code 13) and falling, others showing varying degree of damage and falling (Codes 11, 13, 6, 5). Needles damaged in the terminal regrowth	Accelerated defoliation of stems, leaves senescing, color not normal	Stems completely defoliated (Code 6) About 25-30% stems dead (Code 7)	

Table 4-6. Average densities of woody stems (> 50 cm) in control, herbicide and mechanicaly site preparation Blocks 1 to 3 of the Grande Prairie study

Block	Year sampled	Average[a] number of stems/ha in treatment plots[b]					
		Control	LH	LH + DT	HH	HH + DT	DD
Block 1	1986[c]	53012	62868	58360	54012	45548	47932
	1987	54228	45692	36428	49120	34560	240
	1988	73160	39704	22640	34824	15132	1748
	1989[d]	79200	32560	N.S.[e]	25120	N.S.	4293
Block 2	1986	57280	74520	66360	77068	48440	92788
	1987	73012	90600	55372	71612	37080	40
	1988	82452	93548	43440	52920	15812	1920
	1989	86853	107413	67333	44080	27387	12267
Block 3	1986	49508	42520	60788	59772	43360	47000
	1987	55840	60440	39160	65052	32852	12
	1988	65452	56372	35852	49800	22892	640
	1989	65627	59440	N.S.	51680	N.S.	7253

[a]Average = mean of 30 5 m × 5 m plots per treatment per block.

[2]Controls = no herbicide or mechanical treatment, LH and HH = plots treated with PRONONE 10G at 2 and 4 kg hexazinone/ha respectively, DT = Disk-trenching, DD = Rome Disk.

[c]All 1986 values are pretreatment values.

[d]Sampling intensity in 1989 was 50% of the 1986-88 levels.

[e]Not sampled in 1989.

summaries were prepared for all stems (> 50 cm) for all species, for all aspen stems, and aspen stems in different height classes (Table 4-6 to 4-8).

Stem density data for 1986 to 1988 from control, herbicide alone, and in combination with mechanical treatments were tested for departure from normality (by moment estimates of kurtosis and skewness, goodness-of-fit test using the Kolmogorov-Smirnov procedure, and homogeneity of variances using Bartlett's test'. Details of these aspects are dealt with by Fairbarns[4]. No data sets were found to be normally distributed, and most variances could not be successfully transferred into statistically tractable forms because of strong platy kurtosis. As a result non-parametric tests for analysis of variance among treatments and mean separation were employed.

The density data from Method II were analyzed for variances among treatments by using Friendman's nonparametric test for a randomized complete block design ($P = 0.05$) and Tukey's procedure for ranked data in a randomized block analysis of means separation at $P = 0.05$ (Zar 1980). Percent change in density from 1986 to another year (x) was calculated as $[(x-1986)/1986] \times 100$.

4.3.3 Vegetation Cover

Over 90% of the species in plots were forbs, graminoids or woody species less than 50 cm in height. Detailed quadrat data were collected in all nonmechanically treated plots of Method II (120 quadrats per treatment plot). In each 1 m × 1 m quadrat, all species present at a particular sampling time were noted. A comprehensive list of species was prepared (Appendix A).

The abundance of each species and vegetation stratum was visually estimated by cover class in order to document changes in cover resulting from different vegetation management methods. Species with less than 1% cover were placed in the 0.5% cover class. Cover values of over 1% were classed by increments of 10% and designated by the midpoint of that class (e.g., *Cornus canadensis* at 17% would be placed in the 10-20% class designated by 15%). All cover estimates were made between July and August. The first survey was conducted in 1986 (prior to treatment) and subsequent surveys in summers of 1987, 1988, and 1989.

In mechanically treated plots, permanent plots could not be reestablished after plots were disktrenched or double disked. Initial vegetation was described in general terms and post-treatment vegetation was monitored as outlined below to obtain a general measure of vegetation cover, degree of disturbance, and vegetation recovery following mechanical treatments.

In 1986 baseline vegetation conditions were noted in all environment subplots. Each subplot was divided into four quarters as in the shrub counts (Fig. 4-5) and the covers of the graminoid (G), forb and dwarf shrub (F), medium shrub (A), and tall shrub (B) strata were obtained in each subplot quarter. In 1986 stratum cover was estimated in 25% cover classes. Up to three leading species were listed for each stratum.

Disk-trenching in 1987 created three habitat types on DT plots: berms, trenches and inter-trench areas. Subsequent sampling was limited to circular quadrats (50 cm diameter) in which the cover of each vegetation stratum and up to three leading species were estimated by 25% cover classes. The

---

[4]Fairbarns, M.D. Vegetation dynamics following a catastrophic herbicide disturbance. M.Sc. Thesis, Univ. Alberta, Edmonton, Alta. (In preparation.)

quadrats were centered on crop seedlings which were planted primarily in trenched areas. The sampling was restricted to alternating subplots (5 m × 5 m) of LH-DT, HH-DT, and DD treatments in the Method II (site preparation) area (treatment plots 3, 4) and all treatments except DD plots in the Method I area (Fig. 4-3). The cover of mineral soil, forest litter, exposed F & H layer materials and slash were estimated to 25% cover class. In 1989 for reasons of time and PY constraints, vegetation cover estimates for total cover by strata and by species were done in eight quadrats from DD plots in Block 2 of Method II and in 8 quadrats from each of three habitats (berm, trench and intertrench) in LH-DT and HH-DT plots in Block 2 of Method II. These data are analogous to that collected on control, LH and HH plots of Method II. The data will yield valuable information on the degree of disturbance by disk-trenching and on vegetation cover on three types of habitats created by disk-trenching.

4.3.3.1 Analysis of the species presence and cover data from control and PRONONE 10G treated plots

As with the stem density data, only data from control and herbicide treatment plots of Method II were analyzed in detail. The effect of the PRONONE and mechanical treatments applied in the spring and summer of 1989 are not expected to be realized until the end of the 1990 growing season. Further sampling is essential for the years 1990-91 and 1993-94. As mentioned earlier, the 1986 cover data from disk-trenched and double-disked plots of Method II are not directly compared with other years because the method of data collection and size of sample area were different. These differences were unavoidable because the mechanical treatments in 1987 precluded the use of permanently marked plots.

a) Species richness and total number of species in treatment plots

The number of species per 1 m × 1 m quadrat in treatment plots of each block were enumerated for 1986 to 1989 separately to follow species richness in treatment plots (Table 4-12). Also the total number of species before and after the treatments were determined for years 1986 to 1988 (Table 4-12).

b) Similarity among treatment plots

Similarities among treatments before treatment application and total change in treatments over time based on frequency of occurrence of species and their cover were analyzed by the quantitative form of Sorensen's index and by Euclidean distances (Mueller-Dombois and Ellenberg 1974).

Sorenson's index of similarity in its quantitative form (Motyka Index) was calculated as follows:

$$SI = \frac{2Mw}{MA+MB}$$

where Mw = sum of smaller frequency values of species common to plots A and B
MA = sum of frequency values in plot A
MB = sum of frequency values in plot B

Mean cover within a plot was substituted for plot frequency in order to calculate cover frequency.

Euclidean distance (ED) of dissimilarity between two plots (or two years for the same plot) was calculated as:

$$ED=\sqrt{\sum_{i=1}^{s}(X_{ij}-X_{ik})^2}$$

where S = number of species
X_{ij} = average frequency of species i in jth and kth treatment plot or year

The indices were calculated for years 1986 to 1987 (Table 4-13).

c) **Changes in species cover**

Most quadrats contained many species, however most had cover values closer to or less than 0.1%. Cover values of over 10% were uncommon and consequently data sets were mesokurtotic. The cover class distribution resulted in problems of skewness. The cover data were tested for normality and homogeneity of variance. Serious departures from normality were found in all cases examined todate. Variances within most data sets were also found to be excessively heterogeneous. Non-normal distributions may seriously affect the performance of analysis of variance and were often sufficient to preclude the use of classical ANOVA techniques.

Vegetation changes in the untreated and herbicide-treated areas were assessed at both the vegetation strata and individual species levels. Cover class frequencies were calculated for each vegetation stratum and each leading species for the years 1986-1989 (Tables 4-13 to 4-18). Species changes were further assessed by calculating the number of quadrats in which cover increased, decreased, or did not change. Only species with median cover class values of 5% or more were considered (Table 4-19).

4.4 RESULTS AND IMPLICATIONS

4.4.1 Symptomology and Evaluation of Herbicide and Insect and Disease Damage

The pretreatment survey for insect and disease damage concluded that aspen regrowth can be seriously infected during summer by *Cibornia whetzellii* (Seaver) resulting in as much as 20% damage of the foliage (Table 4-1 to 4-4 and Fig. 4-7). Though forest tent caterpillar was common, it did not impact the cutover blocks to any observable extent. On aspen during the fall, the damage to terminal branches by leaf and twig blight (*Venturia macerlaris*) was common.

Following the application of hexazinone (PRONONE 10G) on 26 August 1986, typical hexazinone damage symptoms on the foliage were not observable during the fall of 1986. Either the amounts translocated to the foliage were not high enough to produce visible damage symptoms, or the physical processes leading to senescence masked the typical herbicide damage symptoms. Circumstantial presence of herbicide residues in the defoliated twigs collected in October 1986 (Section 6.7)--earlier drying of leaves, and marginal necrosis, and a curly look in some aspen leaves

Figure 4-7. Pretreatment soil surface disturbance and vegetation damage. A-B. Disease and insect damage to Populus tremuloides. **C.** Terrain disturbance and vegetation removal: slash piles and scraping of top soil horizons. **D.** Aerial view of the treatment plots in Block 1. Left to right the treatment plots were: 4 kg hexazinone/ha, 2 kg hexazinone/ha, 4 kg/ha plus disk-trenching, 2 kg/ha plus disk-trenching, no treatment, double-disking.

from high herbicide-treated plots--indicated the release of herbicide in soil and its absorption by plants during the posttreated period in the fall of 1986. Transplants of several species from control areas treated with 2 and 4 kg hexazinone/ha rates produced wilting within 48 of the application of the herbicide under greenhouse conditions. It was followed by necrosis of leaf margin and surface in several species within a week after herbicide application (Fig. 4-8). Biweekly phenological observations were made in a number of species present in ten 1 m × 1 m quadrats in each of the control, high-herbicide, and low-herbicide treatment plots. In control plots, species followed generalized pattern of growth initiation in the spring, expansion and maturation of foliage from the middle of June to August, and leaf senescence and defoliation in September to October. The application of herbicide resulted in varying degrees of foliar necrosis, premature senescence and defoliation, and mortality of entire stem tissues without any regenerative response (Fig. 4-8). Species responses are summarized in Table 4-5 for aspen. The species fall into three categories based on their overall response to the hexazinone at the 4 kg/ha rate.

Category I: Species that developed varying intensities of herbicide damage (chlorosis, marginal necrosis, defoliation) beginning in the middle of June and progressively increasing towards the end of August but interrupted by occasional episodes of regrowth. The regrowth occurred from underground root or stem structures and from axillary and terminal buds or completely on partially defoliated stems. The stems from episodic regeneration usually have elongated internodes. Some of the species that belong to this category were *Aster conspicuus, A. ciliolatus, Epilobium angustifolium, Populus tremuloides, Rosa acicularis, Spiraea betulifolia*, and *Vaccinium myrtilloides*.

Category II: Species that showed a progressive herbicide damage from June to August as in Category I but did not show any regenerative episodes of regrowth from underground root or aboveground stem structures. Some species belonging to this category were *Amelanchier alnifolia, Carex* species, *Calamagrostis canadensis, Fragaria virginiana, Rubus pubescens, Linnaea borealis, Maianthemum canadense, Petasites palmatus, Lathyrus ochroleucus, Oryzopsis asperifolia*, and *Ribes lecustre*.

Category III: Species that showed little or no foliar necrosis. The most intense symptom was the foliar chlorosis early in the growing season and no mortality of aboveground stem or root structures. Species like *Alnus crispa, A. tenuifolia, Corylus cornuta, Cornus canadensis, Galium boreale, Viola rugulosa*, and *Crepis tectorum* belong to this category (Fig. 4-9).

The net result of the herbicide on the phenology was the loss of photosynthetic tissue, premature defoliation, and repeated episodic regrowth in some species.

Neither all individuals of a species nor all species were affected to the same intensity in herbicide-treated plots. Variations depended on the age of the individuals, stem density, and above all the distribution of the PRONONE granules. To evaluate the average effect on each of several species, 20 stems each of several species were collected at 30- or 60-days intervals from late May to September 1987, and characteristic responses were evaluated (Table 4-1). The five to six leading species were similarly sampled in 1988 and 1989 (Tables 4-2 and 4-3).

Quantitative herbicide damage data thus collected indicated that a number of species followed one of the three response patterns (Table 4-1). The low herbicide rate (2 kg hexazinone/ha) had

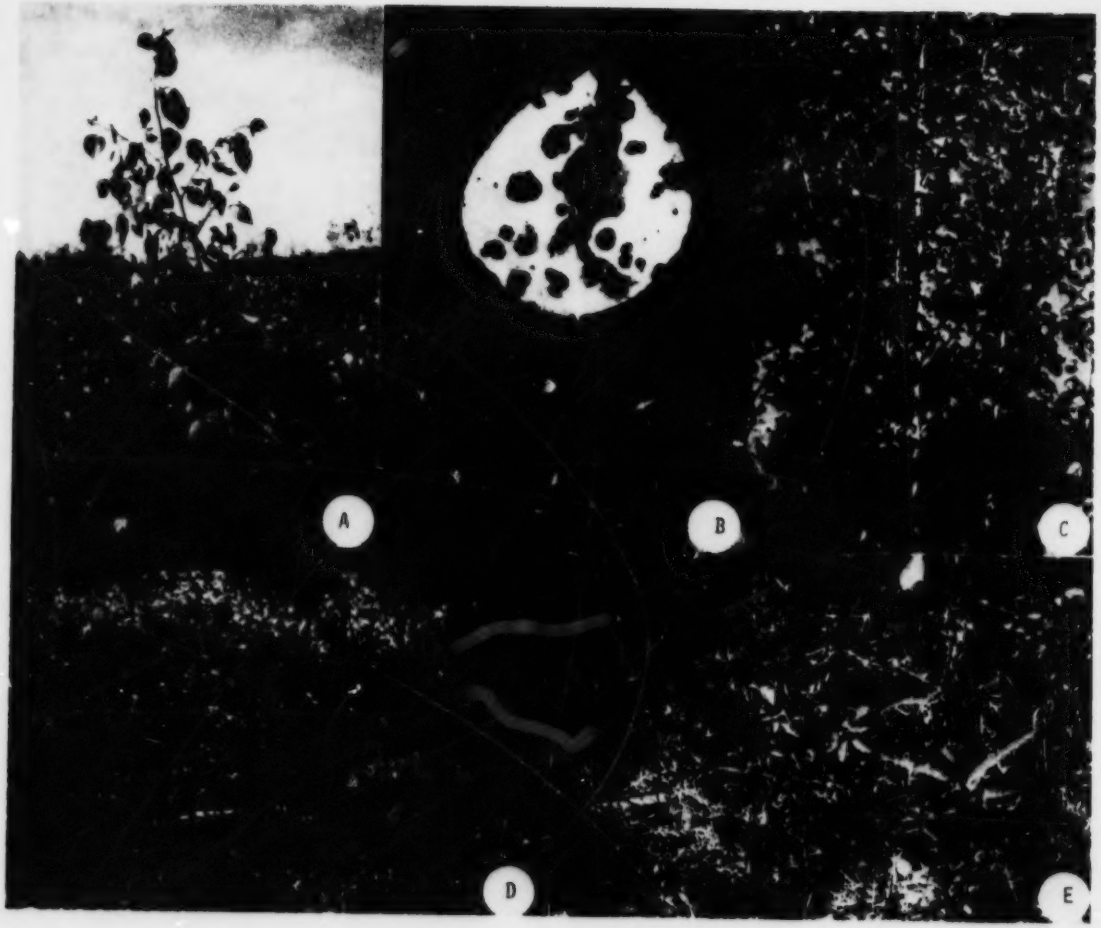

Figure 4-8. Symptoms of hexazinone damage (applied as PRONONE 10G at 4kg/ha rate). A. Initial hexazinone damage: wilting and brown spots on foliage of Populus tremuloides (aspen). **B.** Necrotic spots on P. tremuloides leaf. **C.** Complete necrosis and drying of foliage of P. tremuloides before leaf-fall. Main stem is still alive and supports episodic terminal growth. **D.** Heavy defoliation and stem mortality in aspen. **E.** Complete mortality of Calamagrostis canadensis and forbs with some live individuals of Epilobium angustifolium and Aralia nudicaulis.

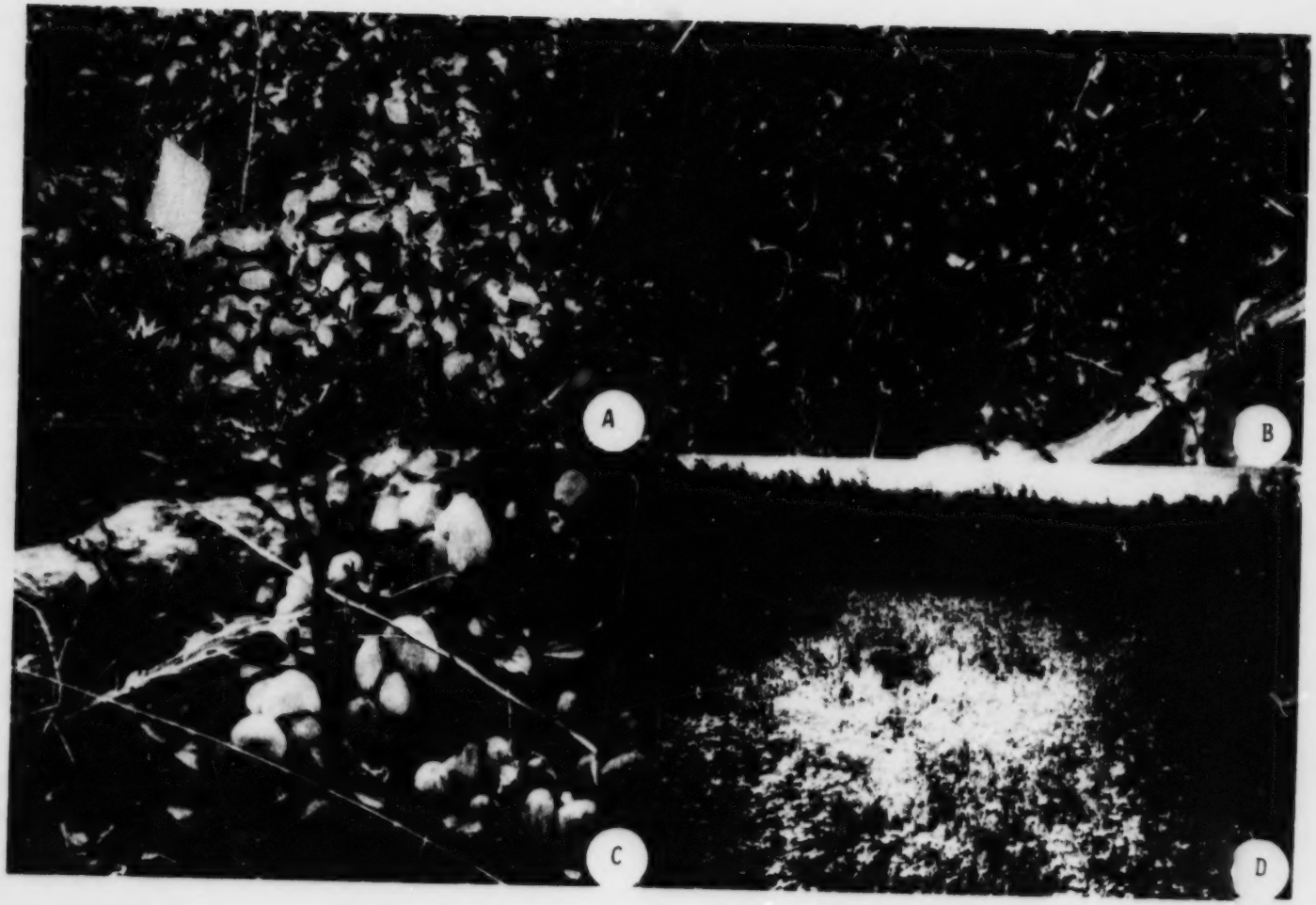

Figure 4-9. Effects of 4 kg hexazinone/ha (as PRONONE™ 10G) on plant species. A. Unaffected Corylus cornuta in a plot where most other species were seriously damaged. **B.** Completely defoliated blueberry (Vaccinium myrtilloides) plants with ripe berries. **C.** Cornus canadensis and fruiting bodies of a fungus resistant to hexazinone. **D.** Invasion of Crepis tectorum (yellow flowers). Photographs **A-D** taken in August 1987, 1st growing season after the 1986 fall application of PRONONE.

little effect on woody and herbaceous species except *Calamagrostis canadensis* and was an ineffective treatment for vegetation management when applied in the fall. Based on the data in Tables 4-1 to 4-3, important conclusions are summarized below:

1) Species differ in their sensitivity to hexazinone. For example, *Calamagrostis* is highly sensitive and can be controlled at application rates of 2 kg hexazinone/ha while *Cornus canadensis* was very lightly affected by the 4 kg hexazinone/ha rate. All woody species were most damaged at 4 kg hexazinone/ha rates except *Corylus, Alnus* and *Betula paprifera*.

2) Damage by insects and diseases was not significant as compared with damage by other treatments including herbicide. Most damage occurred on well-drained mesic conditions.

3) Damage peaked at the end of the second growing season following the herbicide treatments. As a result, first-year assessment following the hexazinone treatments can be excluded for effective use of resources in high cost projects. By the third growing season, some foliage on stems which were previously heavily damaged exhibited light herbicide damage as marginal necrosis, enhanced axillary bud activity, and abnormally elongated internodes. The herbicide PRONONE 10G at 4 kg/ha resulted in a 2-year partial control of vegetation followed by recovery in health and cover of the vegetation (Sections 4.2 and 4.3).

4.4.2 Stem Density Results

The density data for all woody stems and aspen separately are summarized in Tables 4-6 to 4-8. The analysis of 1986 stem density data indicates that the number of total stems per hectare varied greatly among treatment plots and blocks prior to treatment. For example Block 2 plots designated for high-herbicide-plus-mechanical treatment supported 48 440 stems per hectare while in the double-disk (DD) plot there were 92 788 stems per hectare. Similarly in DD-designated plots the pretreatment numbers were 47 932, 92 788, 47 000 stems per hectare in Blocks 1, 2, and 3 respectively. Aspen accounted for over 75% of the total stem density. Aspen varied from 80-96%, 76-89%, and 70-88% in treatment plots of Blocks 1, 2, and 3 respectively. Among replicates of treatments, the percent of aspen ranged from 82-88, 75-96, 79-87, 83-95, 81-92, and 70-85 in the control, LH, LH - DT, HH, HH - DT, and DD plots respectively (Tables 4-6 and 4-7). The within-treatment plots variability was high with a coefficient of variance (CV) of 28-78% indicating very low density to very high density of aspen in the subplots within each treatment plot. The practical difficulties in applying the treatments (especially herbicide application) uniformly to the subplots within each treatment plot added to the variability in stem density which confounded the recognition of the treatment effects on stem density. In general, the analysis of the stem density data suggests strong similarity among plots before treatments, though the densities happened to be lowest in the HH-DT plots (Table 4-6).

The application of PRONONE alone and in combination with disk-trenching and double-disking alone resulted in a varied degree of control of woody stems. At low herbicide rates there was a net increase in the total number of woody stems despite a net decrease of 20% in aspen stems by the end of the 1989 growing season (Figs. 4-10 and 4-11). Low herbicide in combination with disk-trenching resulted in the control of over 40% of woody stems during the first 2 years; however, they recovered to near pretreatment numbers by 1989. The treatment resulted in a decrease of 30% of aspen stems from 1986 levels. The lack of net change in density of woody stems by 1989 was due to an increase in stems of other woody species such as *Rosa, Amelanchier* and *Viburnum*. These species

Table 4-7. Aspen densities (≥ 50 cm) (average and coefficient of variation) in controls and herbicide and mechanically treated plots in Blocks 1 to 3 (site preparation) of the Grande Prairie Study

Block	Year sampled		Average[a] number of stems/ha in treatment plots[b]					
			Control	LH	LH+DT	HH	HH+DT	DD
Block 1	1986	Av	43680	60333	47040	51413	42253	40800
		Cv %	46	69	78	53	77	58
	1987	Av	43760	42693	28413	45960	3154	133
		Cv %	55	67	75	49	65	4
	1988	Av	51947	37613	19280	33280	14693	1547
		Cv %	36	87	84	7	112	157
	1989[c]	Av	43067	30053	NS[d]	21627	NS	3733
		Cv %	37	77	NS	96	NS	124
Block 2	1986	Av	46760	64507	52533	69107	39093	70427
		Cv %	48	49	39	43	66	34
	1987	Av	51960	66507	38707	62373	28067	27
		Cv %	44	43	43	37	73	548
	1988	Av	52253	64080	32413	49280	12520	1453
		Cv %	40	46	45	55	88	178
	1989	Av	44613	58960	35173	39867	15573	7867
		Cv %	33	32	61	54	76	108
Block 3	1986	Av	43800	32093	52733	34907	36320	32880
		Cv %	28	60	42	42	44	34
	1987	Av	44173	44507	30907	33160	24880	0
		Cv %	41	57	5	59	4	N/A
	1988	Av	48147	38813	30333	21187	20200	N.S.
		Cv %	25	52	52	58	67	N.S.
	1989	Av	43227	35227	N.S.	20907	N.S.	4587
		Cv %	19	58	N.S.	6	N.S.	65

[a]Average = mean of 30 5 m × 5 m plots per treatment per block.

[b]Control = no herbicide or mechanical treatment, LH and HH = plots treated with PRONONE 10G at 2 and 4 kg hexazinone/ha respectively, DT = disk trenching, DD = Rome disk.

[c]Sampling intensity in 1989 was 50% of the 1986-88 levels.

[d]Not sampled in 1989.

Table 4-8 Stem densities (stems/ha) for two height classes (50-150 cm and > 150 cm) of aspen in control, and herbicide alone and plus mechanically treated plots in Blocks 1 to 3 (site preparation) of the Grande Prairie study.

Height	Block	Year	Average[a] number of stems/ha in treatment plots[b]					
			Control	LH	LH+DT	HH	HH+DT	DD
Aspen-A	Block 1	1986	42387	59880	46493	50893	42107	40227
		1987	39627	37773	24027	37787	27307	93
		1988	40800	32507	17267	25613	13400	1493
		1989[c]	26880	25840	-[d]	14347	-	3733
	Block 2	1986	45253	61427	48173	66267	38133	66040
		1987	43893	40907	22747	42320	19707	27
		1988	36467	35800	21440	31000	10293	1440
		1989	24080	24107	19467	21360	11707	7307
	Block 3	1986	43320	31533	52360	34307	36093	32000
		1987	40027	31800	23827	27307	19653	27
		1988	35507	22360	26307	16880	16307	-
		1989	23840	14587	-	16160	-	4533
ASPEN-B	Block 1	1986	1293	453	547	520	275	600
		1987	4133	4920	1133	8160	1450	0
		1988	11120	5093	1867	7613	2200	0
		1989	16187	4213	-	7280	-	0
	Block 2	1986	1507	3080	4360	2840	960	4267
		1987	8067	25600	9333	20000	2627	0
		1988	15773	28240	10240	18120	2067	13
		1989	20533	34853	15707	18507	3867	560
	Block 3	1986	480	560	373	600	227	880
		1987	4147	12707	3027	5853	2107	0
		1988	12600	16373	3840	4267	3467	-
		1989	19387	20640	-	4747	-	53

[a]Average = mean of 30 5 m × 5 m plots per treatment per block.
[b]Control = no herbicide or mechanical treatment, LH and HH = plots treated with PRONONE 10G at 2 and 4 kg hexazinone/ha respectively, DT = Disk trenching, DD = Rome disk.
[c]Sampling intensity in 1989 was 50% of the 1986-88 levels.
[d]Not sampled in 1989.

Table 4-9. Summary of stem density data analyses by Friedman's non-parametric test for Randomised Block Analysis of Variance (P = 0.05) and Tukey's Procedure for ranked data in a randomized complete block analysis of means separation (P = 0.05)

Data	Treatment	Mean Comparisons	
		All woody stems	All aspen stems
1986 Density Data	HH	b	a
	LH	b	ab
	HH + DT	a	b
	LH + DT	b	ab
	C	a	ab
1987 Density Data	HH	a	a
	LH	a	a
	HH + DT	b	b
	LH + DT	b	b
	C	a	a
1988 Density Data	HH	c	b
	LH	b	a
	HH + DT	d	d
	LH + DT	c	b
	C	a	a
Absolute change in stem density (1986-88 values)	HH	c	c
	LH	b	b
	HH + DT	c	c
	LH + DT	c	c
	C	a	a
Proportional change in stem (1988/1986 values)	HH	c	c
	LH	b	b
	HH + DT	d	d
	LH + DT	cd	c
	C	a	a

Table 4-10. Pre- (1986) and Post-treatment average stem density of live stems over 50 cm high in control, in herbicide and mechanically treated plots of the Grande Prairie site

Site treatment		*Amelanchier alnifolia* Blocks				*Rosa acicularis* Blocks				*Viburnum edule* Blocks			
		1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
HH	1986	600	5187	22213	9333	987	493	507	662	0	147	0	49
	1987	267	5760	24160	10062	1987	747	1147	1293	0	13	0	4
	1988	80	1173	20773	7342	1000	333	613	649	0	13	0	4
LH	1986	707	6373	6320	4467	267	507	1853	876	13	360	0	124
	1987	760	9467	6013	5413	933	4200	4613	3249	0	720	107	276
	1988	960	13613	7253	7276	547	3920	4640	3036	0	707	80	262
HH-DT	1986	2493	5420	4933	4649	240	733	1107	693	27	907	0	311
	1987	2547	6573	4813	4644	213	760	1267	747	0	227	200	142
	1988	293	960	267	507	107	120	787	338	0	40	120	53
LH-DT	1986	7387	10680	6600	8222	2160	333	200	898	0	133	0	44
	1987	6053	13027	6587	8556	1053	1000	413	822	0	133	53	62
	1988	1293	7533	2373	3733	1627	653	1347	1209	0	67	27	31
C	1986	5107	7493	4960	5853	1213	480	213	636	27	147	0	58
	1987	6400	16120	10187	10902	720	1867	947	1178	0	213	0	71
	1988	11880	20467	13520	15289	2933	3493	2507	2978	13	520	0	178
DD	1986	4600	4240	12053	6964	1200	320	1027	849	53	0	0	18
	1987	0	13	13	9	0	0	0	0	0	0	0	0
	1988	67	27	0	312	13	0	0	4	0	0	0	0

[a]Block average = mean of 30 5 m × 5 m plots per treatment per block.

[b]Controls = no herbicide or mechanical treatment, LH and HH = Plots treated with PRONONE 10G at 2 and 4 kg hexazinone/ha respectively, DT = Disk trenching, DD = Double disk.

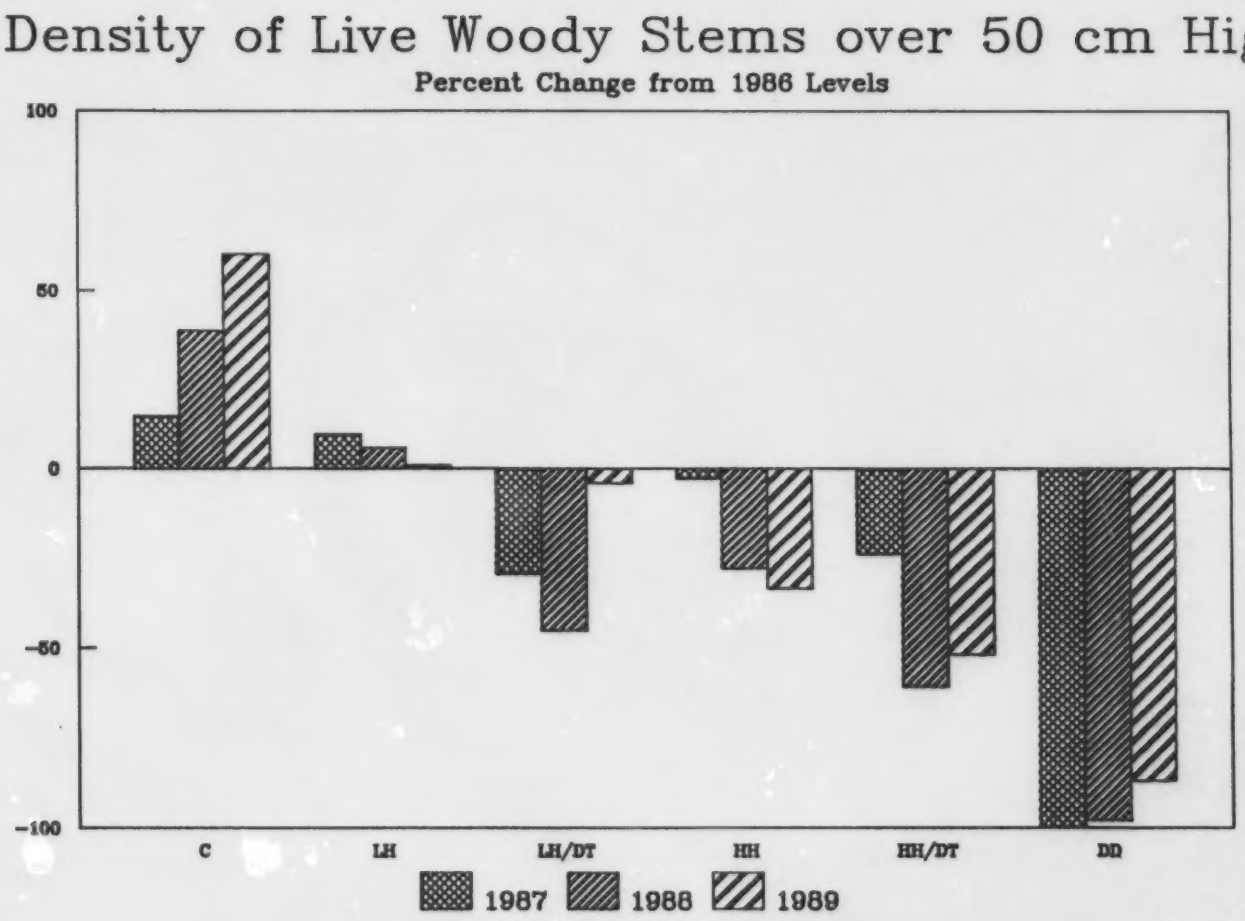

Figure 4-10. Percentage change in density of live woody stems over 50 cm high.

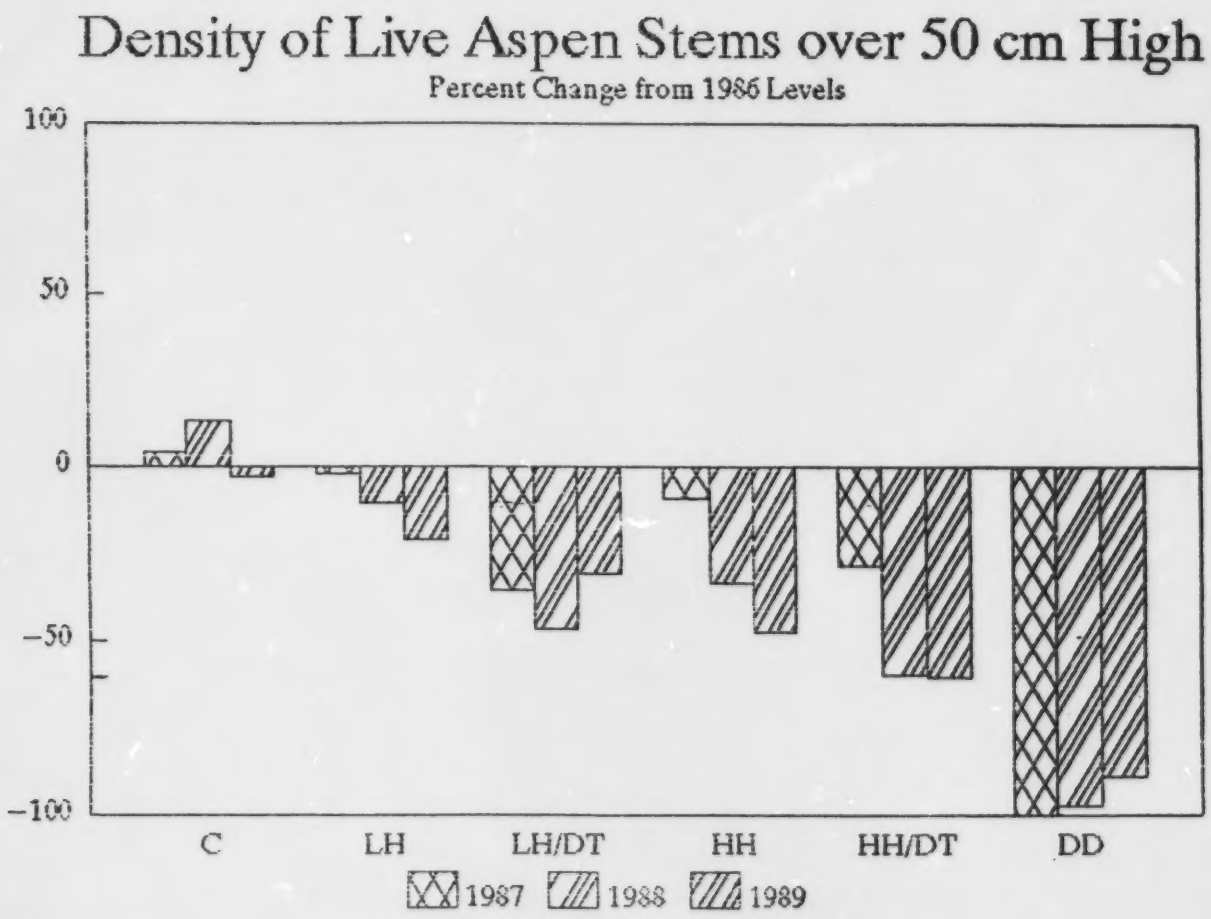

Figure 4-11. Percentage change in density of live aspen stems over 50 cm high.

should be assessed for their competitive stress on crop seedlings and their importance as browse for wildlife. The shift in species may affect the quality and quantity of browse available to wildlife. High herbicide rate alone and in combination with disk-trenching resulted in a 40% and 50% control of woody stems and 50% and 60% control of aspen stems by 1989 respectively (Figs. 4-10 and 4-11). Double-disking resulted in virtually eliminating the woody species for the first 2 years following the treatment and a 10% recovery during the 3rd year (1989).

The statistical analyses of the 1986-88 data for all treatments except double-disking are summarized in Table 4-9. The 1986 stem density data (both for all species and for aspen) were very similar among treatment plots. Herbicide application in the late summer 1986 had little immediate impact on live stem density. The decrease in 1987 density reflects the effect of disk- trenching and probably not the herbicide effects. Nonparametric analyses identified the presence of two distinct density groups: one consisting of untreated and herbicide-treated plots, and the other of plots that were mechanically disk-trenched. Analysis of both the total number of live stems and the number of live aspen stems showed similar results. The reduction in stem density in combined herbicide and mechanical treatments was primarily due to mechanical and 30% due to herbicide effects during 1987 (Fig. 4-10). The effects of all treatments peaked by the end 1988. The effects of mechanical treatments on total live stems had disappeared by the end of 1989. Most of the increase in total number of stems in controls was due to an increase in non-aspen species such as *Amelanchier alnifolia, Rosa acicularis* and *Viburnum edule*. The number of aspen stems over 50 cm did not change much in controls from 1986 to 1989. There was some increase in aspen stems in LH-DT treated plots and DD plots since the treatments were applied (Figs. 4-10 and 4-11). High herbicide rate and other drastic mechanical treatments had a catastrophic effect on nontarget species (Table 4-10) for at least 2 years. The dynamics of the non-aspen species should be examined from the point of view of nonfibre uses. The stem density data should be collected at a future time when the seedlings have reached a free-to-grow stage and when the impacts and benefits of the management of woody species could be fully assessed. This would enable the forest managers to optimize control levels of competing vegetation to achieve a balance between maximum growth of crop seedlings and minimum impact on nontarget species.

4.4.3 Vegetation Cover and Species Presence

4.4.3.1 Species presence, richness, and plot similarity

Over 110 plant species were identified and recorded for their occurrence in the vegetation samples from the study area (Appendix A).

Prior to the treatments, species richness varied within plots within years with CVs of 13-22%. A considerable post treatment variation occurred among treatments within each block and among plots within each treatment (Table 4-11). 1987 species richness on quadrats basis decreased as a result of herbicide treatment. In 1988 species richness in the LH treatments reached that of 1986 level but it continued to be low in HH plots.

The total number of species in treatment plots in LH and HH decreased in 1989 as a result of herbicide treatment but recovered in 1988.

There were large initial variations in species composition among plots of each block and among plots of each proposed treatment. Differences and similarities in the frequency and cover of species are summarized in Table 4-12. The following conclusions can be drawn based on the results todate:

Table 4-11 Species richness and number of species in control and herbicide-treated plots in 1986 to 1989

Treatment		Species Richness[a]				Total number of species in treatment plots			
		1986	1987	1988	1989	1986	1987	1988	1989[b]
Control	B1	20.6 ± 3.1	22.0 ± 3.3	24.1 ± 3.3	22.0 ± 2.8	69	71	79	57
	B2	20.7 ± 2.8	22.0 ± 3.6	23.6 ± 3.5	22.9 ± 2.8	68	78	80	60
	B3	18.8 ± 2.5	19.2 ± 2.4	20.0 ± 3.1	-	65	71	74	-
LH	B1	17.4 ± 3.8	10.8 ± 3.3	11.4 ± 5.2	-	63	59	61	-
	B2	22.2 ± 3.6	18.5 ± 4.0	21.2 ± 4.0	19.1 ± 3.7	74	77	84	51
	B3	17.8 ± 3.1	13.7 ± 5.1	17.2 ± 3.4	-	78	68	93	-
HH	B1	18.2 ± 3.5	10.4 ± 2.6	13.7 ± 4.5	13.9 ± 4.1	58	53	71	55
	B2	21.6 ± 3.4	13.2 ± 3.2	16.3 ± 4.0	15.3 ± 3.4	75	69	87	64
	B3	18.9 ± 3.4	14.1 ± 3.6	12.1 ± 5.5	18.5 ± 3.1	71	59	72	51

[a]Species richness = average number of species per 1 m × 1 m quadrat based on 120 quadrats.

[b]No. of species in 1989 based on 25% sample size of that in 1986 to 88.

Table 4-12. Vegetation dissimilarity based on species frequency[a] and Cover[b]

		Change over time					Differences within years		
		Block 1	Block 2	Block 3			Block 1	Block 2	Block 3
		Euclidean Distance based on species frequencies (high values indicate dissimilarity							
Control	1986/1987	60	56	70	1986	control/low	132	109	143
	1986/1988	111	88	119		control/high	113	133	191
	1987/1988	81	51	70		low/high	88	97	175
Low herbicide	1986/1987	187	140	149	1987	control/low	247	164	207
	1986/1988	202	125	105		control/high	268	233	241
	1987/1988	65	76	101		low/high	98	140	169
High herbicide	1986/1987	238	214	70	1988	control/low	275	154	194
	1986/1988	222	202	119		control/high	266	254	291
	1987/1988	114	124	70		low/high	102	169	235
	Sorensen's Quantitative Index based on species frequencies (low values indicate dissimilarity)								
Control	1986/1987	93	94	92	1986	control/low	84	88	80
	1986/1988	88	91	89		control/high	86	85	77
	1987/1988	92	94	92		low/high	89	90	77
Low herbicide	1986/1987	73	86	81	1987	control/low	63	82	70
	1986/1988	73	87	84		control/high	61	70	66
	1987/1988	85	91	85		low/high	79	79	73
High herbicide	1986/1987	67	73	77	1988	control/low	61	83	72
	1986/1988	71	77	77		control/high	65	69	64
	1987/1988	79	80	74		low/high	80	77	68

Table 4-12 (continued). Vegetation dissimilarity based on species frequency and cover

		Euclidean distance based on average vegetation cover (high values indicate dissimilarity							
Control	1986/1987	4.9	5.5	6.7	1986	control/low	6.6	7.9	10.2
	1986/1988	6.3	7.4	9.3		control/high	7.6	.80	15.3
	1987/1988	4.4	5.3	7.9		low/high	3.5	5.0	16.6
Low	1986/1987	13.3	9.6	19.5	1987	control/low	14.0	12.8	19.7
herbicide	1986/1988	12.9	11.7	18.5		control/high	15.2	15.8	24.6
	1987/1988	3.8	6.0	12.2		low/high	4.0	11.8	10.9
High	1986/1987	15.2	17.5	14.2	1988	control/low	13.1	10.5	13.0
herbicide	1986/1988	12.5	15.9	13.4		control/high	12.1	13.8	19.2
	1987/1988	7.2	8.0	8.0		low/high	5.9	7.9	19.2
		Sorensen's Quantitative Index based on average cover (low values indicate dissimilarity)							
Control	1986/1987	88	90	88	1986	control/low	80	84	78
	1986/1988	85	87	82		control/high	78	82	70
	1987/1988	88	89	85		low/high	90	88	66
Low	1986/1987	57	76	61	1987	control/low	54	70	52
herbicide	1986/1988	60	76	72		control/high	48	54	39
	1987/1988	83	85	71		low/high	77	65	51
High	1986/1987	48	52	49	1988	control/low	57	75	69
herbicide	1986/1988	59	61	58		control/high	60	62	48
	1987/1988	70	73	64		low/high	78	75	54

[a]Frequency is number of quadrats (out of 120) in which a species was present.

[b]Cover is the average vegetation cover in a treatment plot.

1) Prior to the application of treatments, the plots within blocks and within treatments were quite similar and the magnitude of differences due to natural vegetation changes were small as demonstrated by Euclidean distances and similarity indices.

2) Differences between controls and LH and HH plots prior to treatment application varied considerably among blocks.

3) Greater changes in vegetation occurred in controls from 1986 to 1987 than from 1987 to 1988.

4) In plots treated with LH rates (2 kg hexazinone/ha) the greatest changes occurred during the first growing season (1986/1987) following treatments, while in the HH plots (4 kg hexazinone/ha) changes of greater magnitudes due to treatments occurred in 1987 and continued into 1988.

Changes in the frequency of occurrence of leading species in the herbicide and control treatments were analyzed using the data pooled from the three blocks (replicates). The results of this analysis for years 1986 to 1989 are summarized in Table 4-13. In control plots, frequency increased in 65% of the species from 1986 to 1989, 25% of the species showed no significant change, and only 10% were less frequent in 1989 than in 1986. Frequency changes among the 57 leading species (occurring in ≥ 20% of quadrats within one or more treatments in one or more years) are presented in Table 4-13. About 70% of the 57 species listed in the table suffered a significant decrease in their frequency as a result of herbicide application at both 2 kg (LH) and 4 kg (HH) hexazinone/ha rates during the first growing season (1987) following the fall application of the herbicide. There was a significant recovery during the second growing season (1988); however, 50 and 70% of species in LH and HH treatments, respectively, showed an overall net decrease in frequency from the pretreatment levels. The recovery continued into the 1989 growing season except in very sensitive species (*Calamagrostis canadensis, Elymus innovatus, Mertensia paniculata, Oryzopsis asperifolia, Petasites palmatus, Pyrola asarifolia, Rubus pubescens, Spiraea betulifolia*, and *Vicia americana*).

The results of the frequency data agree with the trends found in stem density and cover changes of leading species (Sections 4.4.2 and 4.4.3.2); however, it is important to note that vegetation was constantly changing even in control plots following logging. It is highly improbable that herbicide treatments resulted in a permanent loss of any species. Species frequencies generally decreased in both the LH and HH treatments but the decreases tended to be greatest in the HH treatment. First-year effects were similar for LH and HH rates in a controlled herbicide application study on very small plots. The herbicide was hand-applied (to ensure homogeneous distribution) in spring in contrast to aerial and fall-application on operational experimental plots. The vegetation even in these plots recovered more rapidly in LH than in HH plots. The results of the controlled application study will appear as a M.Sc. Thesis by M.D. Fairbarns[5].

4.4.3.2 Vegetation cover

Changes in the vegetation cover in control and treated plots were considered at various levels of vegetational organization: total cover by stratum (shrubs over 150 m, shrubs 50-150 cm, forbs, graminoids, mosses), by individual species, and by species complexes. The former two will be

---

[5]Fairbarns, M.D. 1990. Vegetation Dynamics following catastrophic herbicide disturbance. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada. (In Preparation).

Table 4-13. Frequency of occurrence of leading species by year and treatment, with 95% binomial confidence limits

Species	Year	Herbicide Treatment (kg hexazinone/ha)								
		4			2			0		
		L	O	U	L	O	U	L	O	U
Achillaea millefolium	1986	10	13	17	7	10	14	9	13	17
	1987	0	1	3	1	2	4	14	18	23
	1988	11	15	19	4	7	10	19	23	28
	1989	12	20	30	0	0	12	31	43	57
Agropyron trachycaulum	1986	18	22	27	7	10	14	8	11	15
	1987	1	2	4	1	2	4	8	11	14
	1988	16	19	24	9	12	16	10	14	18
	1989	13	21	31	1	7	22	4	10	21
Agrostis scabra	1986	13	16	20	13	17	21	11	15	19
	1987	1	1	3	1	3	5	11	15	19
	1988	20	24	29	10	14	18	11	14	18
	1989	21	30	41	4	13	31	13	23	36
Amelanchier alnifolia (50-150 cm)	1986	22	27	31	15	19	23	24	28	33
	1987	21	25	30	15	19	24	28	33	38
	1988	16	20	25	13	17	21	33	38	43
Amelanchier alnifolia (<50 cm)	1986	37	42	48	23	28	33	32	37	42
	1987	27	32	37	20	24	29	35	40	46
	1988	27	31	36	23	28	33	41	47	52
Apocynum androsaemifolium	1986	10	14	18	1	1	3	2	4	6
	1987	16	20	25	2	3	5	2	3	6
	1988	22	26	31	1	3	5	1	2	4
Arabis holboellii	1986	0	0	1	0	0	1	0	0	1
	1987	0	0	1	0	0	1	0	0	1
	1988	11	15	19	0	0	1	0	0	1
Aralia nudicaulis	1986	50	56	61	53	58	63	62	67	72
	1987	54	60	65	56	61	66	62	67	72
	1988	39	44	49	56	61	66	64	69	73
	1989	51	62	72	83	97	100	66	78	88
Arenaria lateriflora	1986	4	6	9	9	12	16	4	6	9
	1987	0	1	3	1	3	5	9	13	16
	1988	6	8	12	5	7	10	9	12	16
Arnica cordifolia	1986	6	8	12	17	21	26	20	24	29
	1987	1	2	4	0	0	1	18	22	26
	1988	1	2	4	9	12	16	14	18	23

Table 4-13 (cont'd)

Aster ciliolatus	1986	79	84	87	69	74	78	65	70	74
	1987	28	32	37	50	56	61	72	77	81
	1988	59	64	69	57	63	68	81	86	89
	1989	75	84	91	69	87	96	73	85	93
Aster conspicuus	1986	73	77	81	70	75	79	88	91	94
	1987	50	55	60	58	63	68	91	94	96
	1988	64	69	73	63	68	73	91	94	96
	1989	65	76	84	44	63	80	86	95	99
Bromus inermis	1986	13	17	21	7	10	14	11	15	19
	1987	1	3	5	1	3	5	14	18	23
	1988	9	13	17	8	11	15	21	26	31
	1989	0	1	6	0	0	12	0	0	6
Calamagrostis canadensis	1986	68	73	77	77	81	85	82	86	89
	1987	5	7	10	35	40	46	90	93	95
	1988	13	17	21	34	39	44	90	93	95
	1989	9	16	25	25	43	62	84	93	98
Castilleja miniata	1986	1	2	4	1	3	5	7	10	14
	1987	1	1	3	2	3	6	21	26	31
	1988	2	3	5	3	5	8	25	30	35
Cornus canadensis	1986	72	77	81	75	80	84	95	97	98
	1987	78	82	86	80	84	88	78	83	86
	1988	79	84	87	79	83	87	80	84	88
	1989	67	77	85	83	97	100	91	98	100
Corylus cornuta (< 50 cm)	1986	2	4	6	7	10	14	2	3	6
	1987	7	10	14	11	15	19	0	0	1
	1988	4	7	10	11	14	18	1	1	3
Crepis tectorum	1986	10	13	17	5	8	11	1	2	4
	1987	3	5	8	1	3	5	4	6	9
	1988	27	32	37	11	14	18	1	3	5
Disporum trachycarpum	1986	6	8	12	3	5	8	1	2	4
	1987	1	3	5	4	6	9	3	4	7
	1988	9	13	17	6	9	13	1	3	5
Elymus innovatus	1986	19	24	29	19	23	28	12	16	20
	1987	1	3	5	3	5	8	11	15	19
	1988	22	26	31	13	16	21	19	23	28
	1989	0	1	6	0	0	12	13	23	36
Epilobium angustifolium	1986	83	86	90	82	86	89	88	91	94
	1987	66	71	75	90	93	95	90	93	95
	1988	73	78	82	81	85	89	82	86	89
	1989	78	87	93	73	90	98	84	93	98

Table 4-13 (cont'd)

Epilobium glandulosum	1986	3	5	8	4	7	10	2	4	6
	1987	0	1	2	3	5	8	0	1	2
	1988	14	18	22	9	13	16	0	1	2
	1989	27	37	47	0	0	12	0	0	6
Equisetum sylvaticum	1986	1	2	4	1	2	4	1	1	3
	1987	0	1	2	0	1	3	2	4	7
	1988	3	5	8	3	6	9	12	16	20
Fragaria virginiana	1986	49	54	59	49	55	60	71	76	80
	1987	0	0	2	28	33	38	57	62	67
	1988	2	4	6	7	10	14	59	64	69
	1989	1	3	9	10	23	42	75	87	94
Galium boreale	1986	81	85	88	68	73	77	79	83	87
	1987	67	72	76	74	78	82	86	90	93
	1988	76	80	84	69	74	78	86	89	93
	1989	75	84	91	73	90	98	73	85	93
Halenia deflexa	1986	1	2	4	0	1	3	3	4	7
	1987	3	5	8	1	2	4	9	12	16
	1988	3	5	8	4	7	10	12	16	20
Hieracium umbellatum	1986	13	17	21	11	14	18	16	19	24
	1987	2	4	6	4	7	10	17	21	26
	1988	7	10	14	7	10	14	26	30	35
Lathyrus ochroleucus	1986	90	93	96	92	95	97	94	96	98
	1987	44	49	54	68	73	77	87	90	93
	1988	17	21	25	51	56	62	74	78	83
	1989	15	23	33	47	67	83	38	52	65
Linnaea borealis	1986	17	21	26	14	18	23	30	35	40
	1987	0	1	2	15	19	24	18	22	27
	1988	0	1	2	7	9	13	26	31	36
Lonicera dioica	1986	7	10	13	14	18	22	9	12	16
	1987	3	5	8	17	21	26	6	9	12
	1988	4	7	10	15	19	24	6	9	12
Lonicera involucrata	1986	13	16	20	19	24	28	16	20	25
	1987	2	3	5	16	19	24	13	16	20
	1988	4	7	10	16	20	25	13	17	21
	1989	0	2	8	10	23	42	15	25	38
Maianthemum canadense	1986	49	54	59	69	74	78	69	749	
	1987	39	45	50	66	71	76	53	58	63
	1988	61	66	71	65	70	75	59	64	69
	1989	47	58	68	54	73	88	59	72	83

Table 4-13 (cont'd)

Mertensia paniculata	1986	29	33	38	24	29	34	11	15	19
	1987	1	1	3	8	11	14	27	32	37
	1988	1	2	4	9	12	16	31	36	41
	1989	0	0	4	15	30	49	8	17	29
Oryzopsis asperifolia	1986	24	29	34	24	28	33	53	58	63
	1987	1	2	4	34	39	44	32	37	43
	1988	10	13	17	16	20	25	38	43	48
	1989	0	0	4	17	33	53	31	43	57
Petasites palmatus	1986	25	29	34	26	31	36	8	11	15
	1987	7	10	14	4	6	9	13	17	21
	1988	8	11	15	11	14	18	13	16	21
	1989	5	10	18	10	23	42	12	22	34
Poa pratensis	1986	1	2	4	0	1	2	1	3	5
	1987		0	0	1	0	1	2	0	01
	1988	9	13	17	2	4	7	2	3	5
Populus tremuloides	1986	87	91	93	86	90	93	91	94	97
(50-100 cm)	1987	89	92	94	86	90	93	94	97	98
	1988	79	83	87	80	84	88	96	98	99
	1989	80	89	95	88	100	100	86	95	99
Populus tremuloides	1986	29	34	39	29	33	38	37	42	47
(>50 cm)	1987	48	53	58	60	65	70	63	68	73
	1988	39	44	50	61	66	71	83	87	91
	1989	56	67	76	88	100	100	82	92	97
Populus tremuloides	1986	86	90	93	88	91	94	89	92	94
(<50 cm)	1987	84	88	91	83	87	90	87	91	93
	1988	77	81	85	76	81	85	91	94	97
	1989	78	87	93	83	97	100	84	93	98
Pyrola asarifolia	1986	11	14	19	13	16	21	21	25	30
	1987	1	3	5	10	13	17	13	17	21
	1988	1	2	4	8	11	14	18	22	26
Ribes oxyacanthoides	1986	3	5	8	9	12	16	2	4	7
	1987	0	1	3	7	10	14	10	13	17
	1988	1	3	5	9	12	16	9	13	17
Rosa acicularis	1986	11	14	18	10	14	18	10	13	17
(50-150 cm)	1987	11	14	18	14	18	23	19	23	28
	1988	12	16	20	23	28	33	25	30	35
Rosa acicularis (< 50 cm)	1986	91	94	96	91	94	96	95	978	
	1987	83	86	90	91	94	96	94	96	98
	1988	79	83	87	86	89	93	97	99	100
	1989	57	68	77	88	100	100	94	100	100

Table 4-13 (cont'd)

Rubus pubescens	1986	47	52	57	47	52	57	47	53	58
	1987	3	5	8	30	35	40	56	61	66
	1988	6	9	12	24	29	34	61	66	71
	1989	1	3	9	23	40	59	45	58	71
Salix spp. (< 50 cm)	1986	4	6	9	8	11	15	6	8	11
	1987	1	3	5	2	4	6	6	8	11
	1988	2	4	6	2	3	6	6	8	11
Shepherdia canadensis	1986	4	7	10	9	12	16	19	23	28
	1987	2	4	7	12	15	19	13	17	21
	1988	3	5	8	9	13	16	16	20	25
Smilacina racemosa	1986	17	21	26	9	12	16	5	7	10
	1987	4	6	9	11	15	19	20	24	29
	1988	6	9	12	10	13	17	18	22	26
Spiraea betulifolia	1986	60	66	71	48	53	58	75	79	83
	1987	42	47	53	69	74	79	79	83	87
	1988	21	26	31	46	51	56	79	83	87
	1989	11	18	27	54	73	88	59	72	83
Symphoricarpos albus	1986	38	43	48	31	36	41	37	42	47
	1987	21	25	30	40	46	51	49	54	59
	1988	30	35	40	33	38	44	53	58	63
	1989	33	43	54	38	57	75	28	40	53
Taraxacum officinale	1986	21	26	31	18	23	27	16	20	24
	1987	2	4	6	11	14	19	19	24	29
	1988	29	34	39	17	21	25	26	30	35
Thalictrum venulosum	1986	36	41	46	9	12	16	3	6	9
	1987	15	19	23	3	5	8	4	7	10
	1988	21	25	30	2	4	7	6	9	12
Vaccinium caespitosum	1986	19	23	28	24	28	33	35	40	46
	1987	13	17	21	14	18	23	24	29	34
	1988	31	36	41	21	25	30	28	33	38
	1989	12	20	30	2	10	27	38	52	65
Vaccinium myrtilloides	1986	2	4	6	3	5	8	0	0	1
	1987	2	4	6	0	0	1	0	0	1
	1988	8	11	15	5	7	10	0	0	2
Viburnum edule	1986	42	48	53	41	46	51	64	69	74
	1987	42	47	53	61	66	71	42	48	53
	1988	31	36	41	42	47	53	48	53	58
	1989	37	48	59	69	87	96	47	60	72

Table 4-13 (cont'd)

Vicia americana	1986	74	78	82	71	76	81	78	82	86
	1987	55	60	65	49	54	60	68	73	78
	1988	23	27	32	37	42	48	49	54	59
	1989	25	34	46	15	30	49	45	58	71
Viola adunca	1986	1	1	3	1	3	5	3	6	9
	1987	9	12	16	4	7	10	3	5	8
	1988	16	21	25	6	9	12	5	7	10
	1989	6	12	21	2	10	27	4	10	21
Viola rugulosa	1986	4	7	10	3	5	8	1	3	5
	1987	13	16	20	3	5	8	5	8	11
	1988	23	28	33	3	6	9	9	13	16

1. Frequency is percentage of quadrats in which species occurs: 1986-88 n=360; 1989: 4 kg/ha n=90; 2 kg/ha n=30; 0 kg/ha n=60.
2. 95% binomial confidence limits calculated according to Burstein (1971).
3. L = lower confidence limit, U = upper confidence limit, O = observed value.
4. Leading species are those which occurred in >20% of the quadrats within one or more treatments in one or more years.

considered in detail in this report. In general, like the number of stems, the pretreatment percent vegetation cover varied greatly among blocks, treatment plots within blocks, and subplots within treatment plots. Changes in vegetation cover reflected postsecondary (postharvest) succession in control plots and herbicide-induced changes in treated plots and fluctuatons due to year-to-year climatic variations. As a result of very large variations, data from all three blocks of Method II were pooled prior to analysis in order to assess general vegetation cover changes discussed in the ensuing text.

a) Changes in vegetation cover by vegetation strata

In control plots vegetation cover in the tall (>150 cm) shrub stratum increased by two cover-classes from 1986 to 1989. The median cover class median changed from 0.0 in 1986 to 5.0 in 1988-89 (Table 4-14). The maximum change was from 1987 to 1988 (first and second growing season following the treatment). This increase was also evident in the aspen stem densities (Table 4-7). Most quadrats were categorized into cover classes with median of 5 and 15% cover. Over the length of the monitoring period there was an optimization of cover in the tall shrub stratum by a decrease in number of quadrats with very low or very high cover. Overall cover did not change in the median shrub stratum. Most quadrats belonged to the cover class with a 15% median, however there was again a shift towards cover classes with medians of 15 and 25 and 45%. The percent cover of forbs in most quadrats varied from 30 to 80%. There was a shift toward a lower median class from 55% to 45% in 1988 with stabilization in 1989. It is evident from the cover class frequency data in Table 4-14 that the cover of forbs shifted toward classes with a midpoint of 35-65%. There was no overall change in graminoid cover. The graminoid cover decreased in quadrats with initial cover of higher than 45% (class midpoint). Cover of mosses and bryophytes did not change appreciably from 1986 to 1988. There was a general drop by one cover class in 1989 (Table 4-13; Fig. 4-16).

The vegetation cover data based on 360 plots clearly show that natural changes in vegetation are operative in the cutover area and most changes are reflected in the cover of tall shrub and forb strata.

The application of PRONONE 10 G at 2 kg hexazinone/ha rate had no overall measurable effect on the cover of medium shrubs, forbs, and mosses and bryophyte strata. Their medians for cover class midpoint were the same as in the controls. The cover of the tall shrubs increased by two cover classes (20%) while the graminoids decreased by one cover class (10%). The changes in cover for the shrub strata showed the same trends as the density of live stems. PRONONE 10G at the 2 kg/ha rate did not achieve the expected goal of reducing the competition either by a reduction in the cover or density of the shrub strata or cover of the forbs and low shrubs (Table 4-14 to 4-15).

The PRONONE 10G application at 4 kg/ha rate resulted in a significant decrease in cover of medium shrubs by one cover class and cover of forbs stratum by 3 cover classes. The control of graminoids were comparable to the 2 kg ai/ha rate (Table 4-16; Fig. 4-11 to 4-15).

The comparison of frequency of quadrats for graminoids in each cover class for 2 kg and 4 kg rates showed that in 1988 only 10% of the quadrats were included in the 5% midpoint cover class for the 4 kg rate as compared to the 16% for the 2 kg rate. Though the median does not reflect the change, these frequencies doubled in 1989 indicating strong recovery of the graminoid species in the third growing season following the herbicide application. The present study points to the fact that if finer levels of changes in the cover are to be detected, percent cover should be measured as a continuous variable rather than as class data. The present procedure proved to be less sensitive when changes were small.

Table 4-14. Cover class frequencies[a] by year for vegetation strata, control treatment

Stratum	Year	Cover Class Midpoint												
		0	0.5	5	15	25	35	45	55	65	75	85	95	Median
Tall Shrubs (>150 cm)	1986	203	105	39	9	3	0	1	0	0	0	0	0	0.0
	1987	110	103	137	7	3	0	0	0	0	0	0	0	0.5
	1988	39	80	190	44	4	2	0	1	0	0	0	0	5.0
	1989[b]	18	36	174	102	24	6	0	0	0	0	0	0	5.0
Medium Shrubs (50-150 cm)	1986	3	12	95	121	70	37	11	7	4	0	0	0	15.0
	1987	5	8	68	115	95	52	14	1	2	0	0	0	15.0
	1988	0	6	53	140	106	32	14	5	2	2	0	0	15.0
	1989	0	0	42	156	102	18	36	6	0	0	0	0	15.0
Forbs and Low Shrubs (<50 cm)	1986	4	3	7	6	11	57	66	65	66	37	37	1	55.0
	1987	0	0	1	2	7	39	57	81	93	50	27	3	55.0
	1988	0	0	3	22	52	71	66	67	45	28	6	0	45.0
	1989	0	0	0	0	24	96	78	54	48	54	6	0	45.0
Graminoids	1986	4	84	168	72	19	3	3	2	3	2	0	0	5.0
	1987	1	68	201	74	13	3	0	0	0	0	0	0	5.0
	1988	0	70	254	31	5	0	0	0	0	0	0	0	5.0
	1989	0	0	198	144	12	6	0	0	0	0	0	0	5.0
Mosses and Bryophytes	1986	27	90	163	57	15	6	2	0	0	0	0	0	5.0
	1987	17	86	153	69	21	9	4	0	0	1	0	0	5.0
	1988	38	90	158	52	17	3	1	0	0	1	0	0	5.0
	1989	36	168	144	12	0	0	0	0	0	0	0	0	0.5

[a]Class frequencies are based on total of 360 quadrats (1986-1988) from three replicate blocks of the treatment.

[b]16.6% sampling intensity in 1989, values multiplied by 6 for comparison.

Table 4-15. Cover class frequencies[a] by year for vegetation strata, low herbicide treatment

Stratum	Year	Cover Class Midpoint												
		0	0.5	5	15	25	35	45	55	65	75	85	95	Median
Tall Shrubs (>150 cm)	1986	231	76	47	5	1	0	0	0	0	0	0	0	0.0
	1987	123	92	128	12	4	0	0	0	0	0	1	0	0.5
	1988	117	54	109	53	21	2	0	2	1	1	0	0	5.0
	1989[b]	0	0	60	108	60	60	60	12	0	0	0	0	25.0
Medium Shrubs (50-150 cm)	1986	29	17	71	98	66	44	22	9	3	1	0	0	15.0
	1987	31	19	86	90	80	40	10	3	1	0	0	0	15.0
	1988	42	22	82	84	72	38	10	8	1	1	0	0	15.0
	1989	0	0	60	144	132	24	0	0	0	0	0	0	15.0
Forbs and Low Shrubs (<50 cm)	1986	0	0	8	21	36	40	64	74	52	29	30	6	55.0
	1987	10	3	7	13	38	62	73	51	65	20	18	0	45.0
	1988	6	1	11	18	30	47	57	73	50	46	17	4	55.0
	1989	0	0	0	0	12	108	96	84	60	0	0	0	45.0
Graminoids	1986	11	97	183	32	14	3	8	2	2	3	3	2	5.0
	1987	72	195	80	8	2	1	0	0	2	0	0	0	0.5
	1988	93	209	53	2	0	0	0	1	0	2	0	0	0.5
	1989	36	216	108	0	0	0	0	0	0	0	0	0	0.5
Mosses and Bryophytes	1986	38	96	124	44	17	12	5	14	5	3	2	0	5.0
	1987	56	93	133	40	25	6	2	1	3	1	0	0	5.0
	1988	43	77	138	47	20	17	11	3	3	1	0	0	5.0
	1989	24	108	204	24	0	0	0	0	0	0	0	0	5.0

[a]Class frequencies are based on a total of 360 quadrats (1986-1988) from three replicate blocks of the treatment.

[b]16.6 % sampling intensity in 1989, values multiplied by 6 for comparison.

Table 4-16. Cover class frequencies[a] by year for vegetation strata, high herbicide treatment

Stratum	Year	Cover Class Midpoint												
		0	0.5	5	15	25	35	45	55	65	75	85	95	Median
Tall Shrubs (>150 cm)	1986	235	64	60	1	0	0	0	0	0	0	0	0	0.0
	1987	173	102	77	6	2	0	0	0	0	0	0	0	0.5
	1988	156	84	91	21	5	1	2	0	0	0	0	0	0.5
	1989[b]	124	72	112	24	28	0	0	0	0	0	0	0	0.5
Medium Shrubs (50-150 cm)	1986	17	33	96	94	62	32	11	8	3	3	1	0	15.0
	1987	24	61	188	59	19	8	1	0	0	0	0	0	5.0
	1988	43	47	133	64	45	18	4	4	1	0	1	0	5.0
	1989	40	28	144	80	48	8	8	0	4	0	0	0	5.0
Forbs and Low Shrubs (<50 cm)	1986	0	0	3	13	30	52	73	68	55	38	26	2	55.0
	1987	2	0	47	124	118	47	15	4	3	0	0	0	25.0
	1988	3	1	5	45	58	79	66	55	28	15	5	0	35.0
	1989	0	12	8	44	44	92	56	44	48	8	4	0	35.0
Graminoids	1986	8	139	166	30	12	5	0	0	0	0	0	0	5.0
	1987	279	80	1	0	0	0	0	0	0	0	0	0	0.0
	1988	77	246	37	0	0	0	0	0	0	0	0	0	0.5
	1989	40	232	72	12	4	0	0	0	0	0	0	0	0.5
Mosses and Bryophytes	1986	52	90	156	46	12	2	1	1	0	0	0	0	5.0
	1987	56	98	134	56	10	5	1	0	0	0	0	0	5.0
	1988	40	81	170	50	10	5	4	0	0	0	0	0	5.0
	1989	48	64	156	56	12	4	4	4	4	4	4	0	5.0

[a]Class frequencies are based on a total of 360 quadrats (1986-1988) from three replicate blocks of the treatment.

[b]16.6 % sampling intensity in 1989, values multiplied by 6 for comparison.

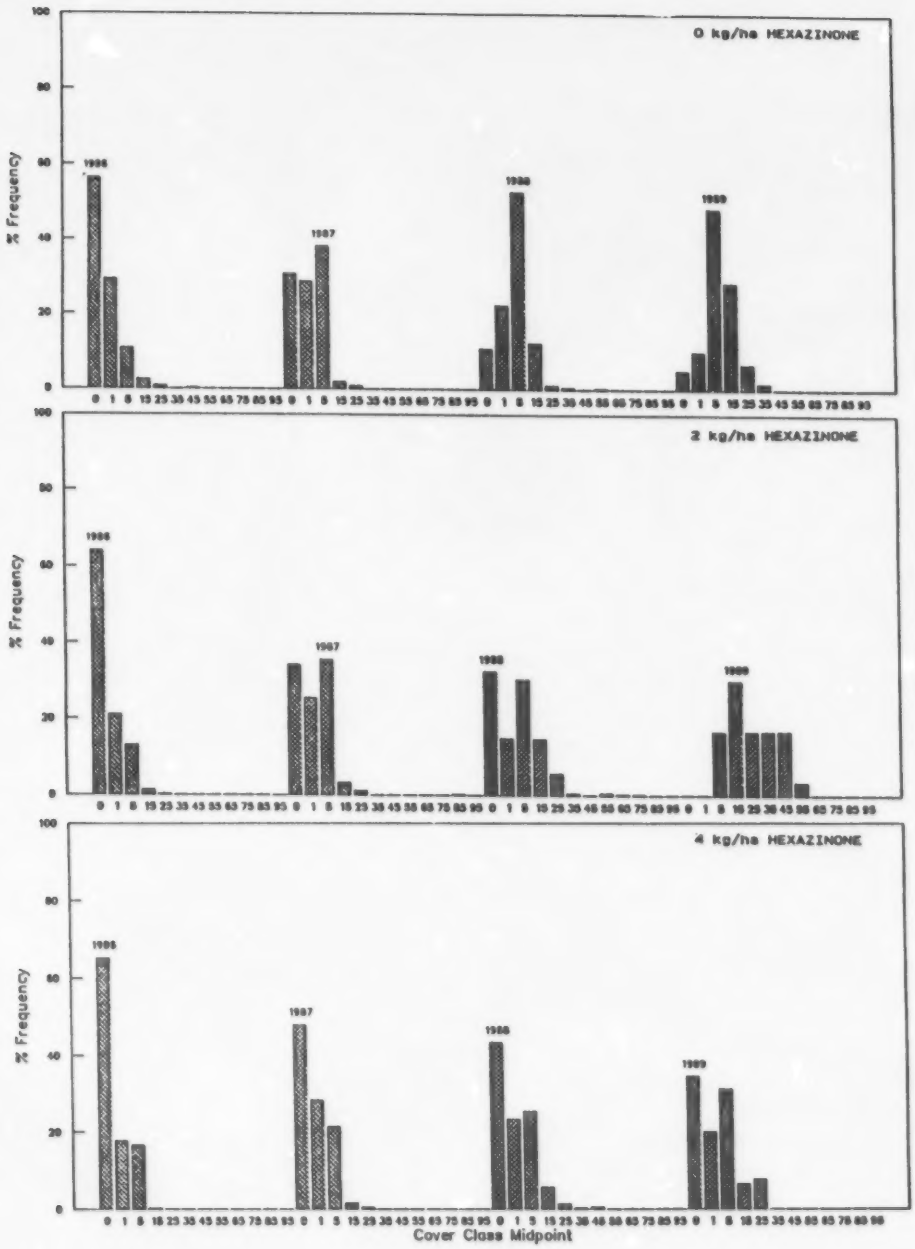

Figure 4-12. Percent frequency of cover classes (1986-1989) for tall shrub foliage in control and hexazinone-treated (as Pronone 10G) plots.

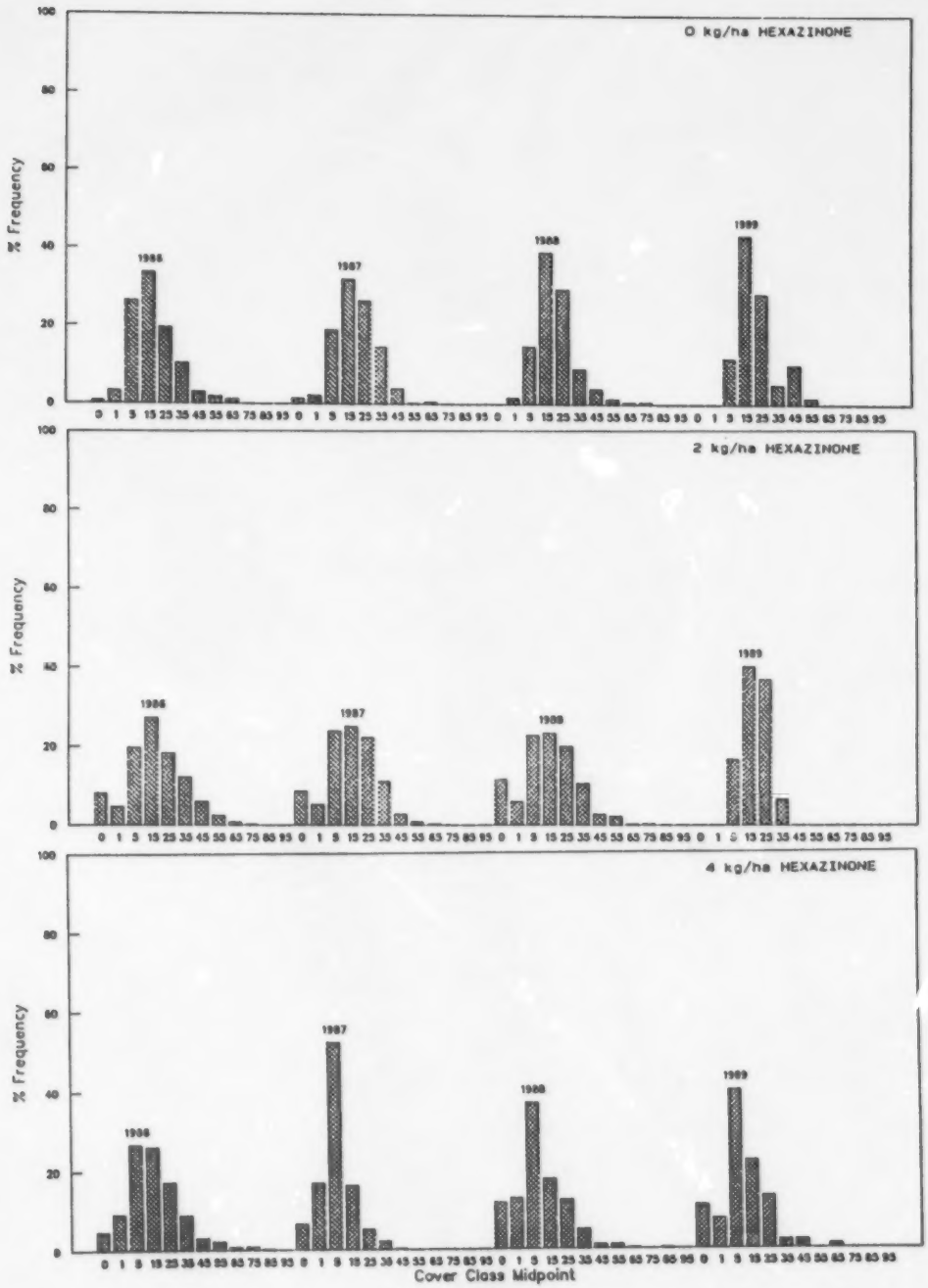

Figure 4-13. Percent frequency of cover classes (1986-1989) for medium shrub foliage in control and hexazinone-treated (as PRONONE 10G) plots.

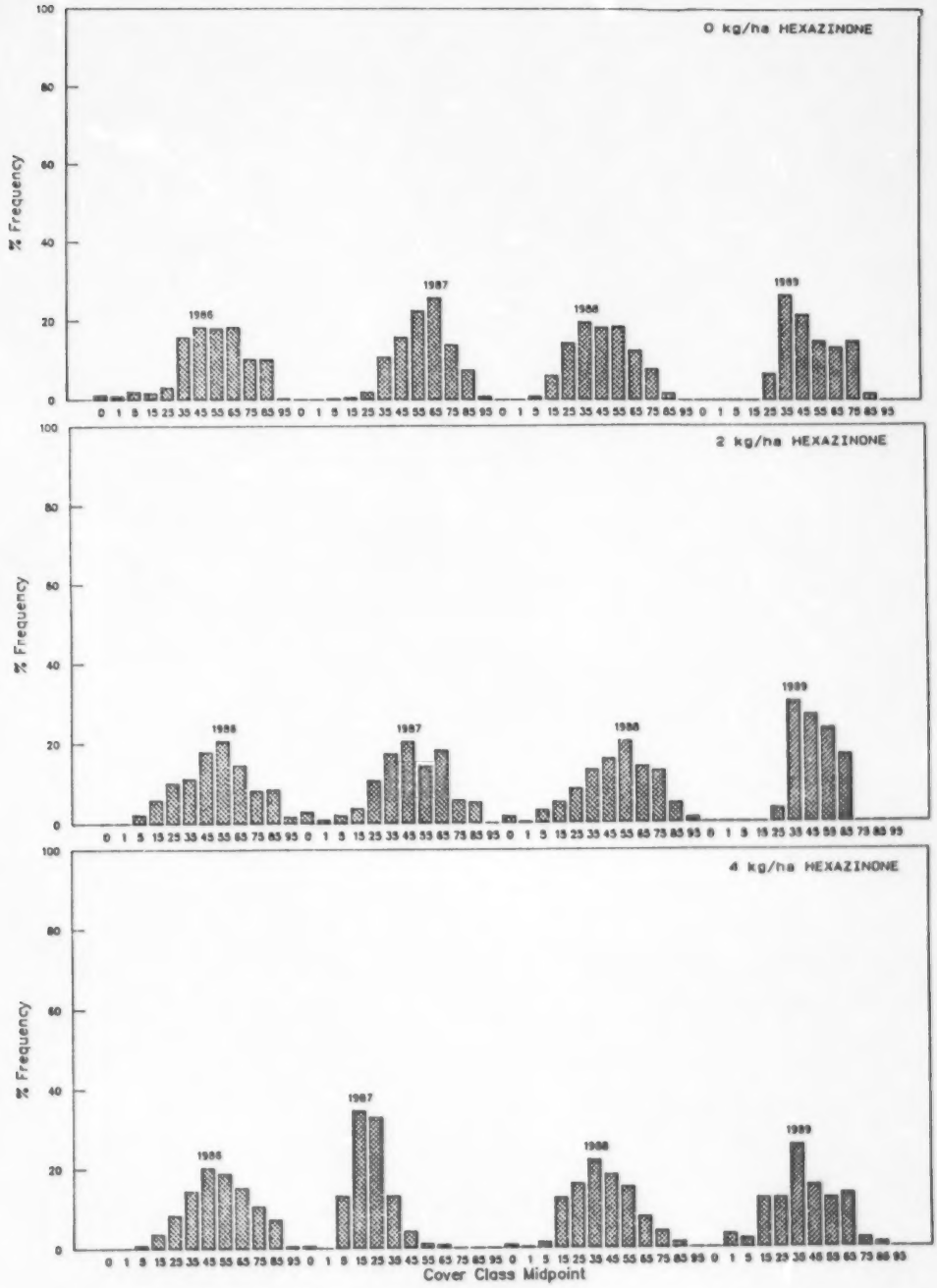

Figure 4-14. Percent frequency of cover classes (1986-1989) for forb and low shrub foliage in control and hexazinone-treated (as PRONONE 10G) plots.

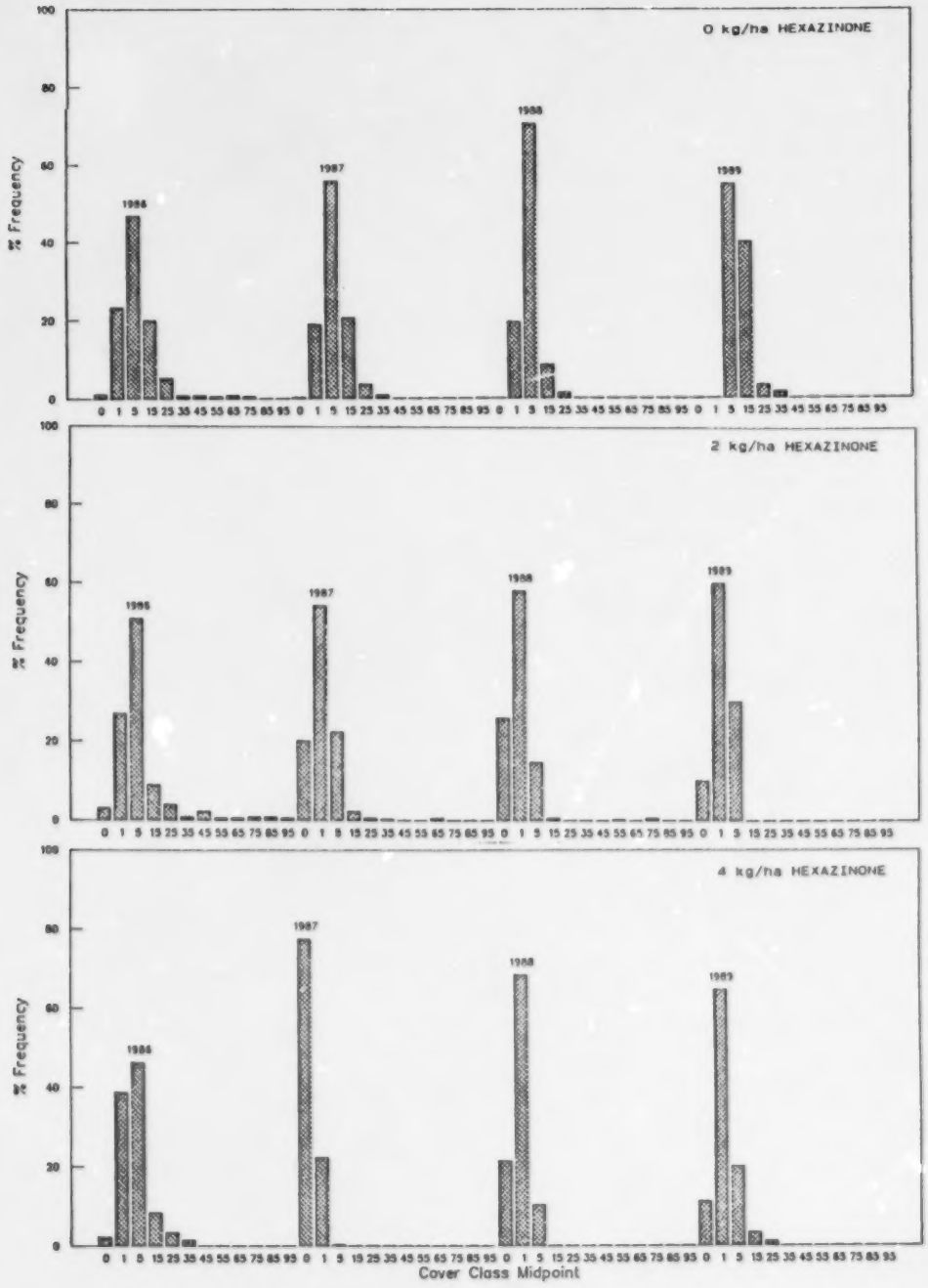

Figure 4-15. Percent frequency of cover classes (1986-1989) for graminoids in control and hexazinone-treated (as PRONONE 10G) plots.

The greatest changes in vegetation in mechanically treated plots was by the partial or complete removal of surface horizons of soils and associated vegetation through terrain disturbance. Before the application of the site preparation and crop release treatments, major terrain disturbance was in the form of slash and slash piles, skid roads and scrape-offs (Fig. 4-7C). The disk-trenching resulted in trenches of varied depths and width and berms of excavated and overturned material on the edges of trenches (Fig. 4-4D). The double-disking resulted in complete terrain disturbance resembling newly broken fields with a complete removal of vegetation cover and exposure of a variety of surface and deep soil horizons (Fig. 4-4E). The pooled data from all blocks is summarized in Table 4-17. Control areas and those treated with herbicide exhibited <20% terrain disturbance in over 80% of the plots, and the disturbance was mostly due to the harvest-related activities. In some plots, there were large amounts of slash and exposure of mineral soil due to scrape-offs.

In disk-trenched areas, 20-60% the surface was disturbed. The disturbance was low in plots where the disk-trencher passed over large stumps. Double-disking resulted in 80-100% surface disturbance (Table 4-17) and areas resembled newly broken fields. In trenched and double-disked areas without any vegetation cover, strong off-site movement of soil and dissolved nutrients were observed during heavy rainfall in July 1987.

The data for vegetation cover around seedings in circular quadrats (50 cm diameter) from mechanically treated plots is summarized in Table 4-18. The greatest vegetation cover occurred in control plots and the least in double-disked areas. Intermediate vegetation cover was recorded in disk-trenched and low herbicide and disk-trenched areas. The cover was lower in high herbicide and disk trenched-areas than the LH-DT but higher than in double-disked (DD) areas. The choice of vegetation control method would depend on the performance of crop seedlings and cost-benefit of each applied method. These assessments would require further sampling of the crop seedlings in the 5th and 8th year following the application of site preparation and crop release treatments to determine the benefits through gains in crop seedling growth and establishment.

b) Changes in vegetation cover by leading species

There are only a small number of species in which cover changes due to natural and imposed factors can be quantified with confidence because the majority of species had low cover values. As a result, cover class data are not suitable for detecting changes in cover class frequencies. For the analysis of cover data for individual species, only those species that had a cover of over 1% in any one of the years (1986-89) of sampling were considered. The data for leading species in control, low-herbicide and high-herbicide treated plots are summarized in Tables 4-19 to 4-21 and in Appendix B.

The changes in cover of leading species were looked at in three different ways: changes in the frequency of different cover classes, changes in the median, and changes in number of quadrats in which either the species cover changed by two or more cover classes or did not change (Table 4-22).

In control plots, the median for percent cover did not change from 1986 to 1989 in *Aralia nudicaulis, Aster conspicuus, A. ciliolatus, Calamagrostis canadensis, Cornus canadensis, Epilobium angustifolium, Populus tremuloides* (50-150 cm), *Rosa acicularis*, and *Spiraea betulifolia*. There was general increase of frequency of cover classes closer to the median and decrease in classes with very high or zero cover. Interestingly in *Populus tremuloides*, cover increased in the tall shrub stratum and drastic decrease occurred in its <50cm stratum. Changes in *Fragaria virginiana, Galium boreale* and *Viburnum edule* were inconsistant. Leguminous species such as *Lathyrus* decreased over the 1986-1989

Table 4-17. Percent surface disturbance in control and treated plots - pooled data from all blocks, 1987

Treatment	No. of plots sampled	Frequency of plots in terrain disturbance classes					
		Percent 1% surface disturbed					
		0-10	11-20	21-40	21-40	41-60	81-100
Control	240	179	44	13	2	1	1
High herbicide (4 kg hexazinone/ha)	120	50	34	25	1	2	8
Low herbicide (2 kg hexazinone/ha)	120	59	36	5	4	8	8
High herbicide + disk-trenching	120	-	1	48	50	11	10
Low herbicide + disk-trenching	120	-	-	35	57	20	8
Disk-trenching	464	-	11	217	202	27	7
Double disking	240	-	-	-	-	-	240

Table 4-18. Total vegetation cover in seedling competition quadrats by percent frequency of quadrats in each cover class, 1987

Treatment	% number[a] of quadrats in each of the cover classes[b]			
	1	2	3	4
Control	28	33	26	13
Low herbicide + disk-trenching (LH + DT)	58	28	9	5
High herbicide + disk-trenching (HH + DT)	75	23	2	-
Disk-trenching (DT)	53	33	11	3
Double-disking (DD)	84	10	4	2

[a]Cover class 1: 0-25%, 2: 26-50%, 3: 51-75%, 4: 76-100%.
[b]n = 109, 150, 145, 349, and 283 in control, LH + DT, HH + DT, DT and DD. Quadrats were circular with a 50 cm diameter.

Table 4-19. Cover class frequencies[a] by year for leading species[b], control treatment

Species	Year	Cover Class Midpoint											Median
		0	+	5	15	25	35	45	55	65	75	85	
Aralia nudicaulis	1986	119	44	175	22								5.0
	1987	119	43	189	8	1							5.0
	1988	113	46	193	7	1							5.0
	1989[c]	78	24	222	24	12							5.0
Aster ciliolatus	1986	109	62	144	36	9							5.0
	1987	83	54	151	42	20	7	2	1				5.0
	1988	52	84	183	40	1							5.0
	1989	54	114	174	18								5.0
Aster conspicuus	1986	31	24	222	73	9			1				5.0
	1987	23	13	268	53	3							5.0
	1988	23	44	254	38	1							5.0
	1989	18	42	264	36								5.0
Calamagrostis canadensis	1986	50	92	149	56	11	1		1				5.0
	1987	26	88	181	52	10	3						5.0
	1988	26	91	217	21	5							5.0
	1989	24	84	192	60								5.0
Cornus canadensis	1986	11	104	229	16								5.0
	1987	63	92	184	20	1							5.0
	1988	58	93	196	13								5.0
	1989	6	108	246									5.0
Epilobium angustifolium	1986	33	36	278	13								5.0
	1987	26	30	274	29	1							5.0
	1988	50	45	243	22								5.0
	1989	24	30	276	30								5.0

Table 4-19 (Cont'd)

Fragaria virginiana	1986	87	66	153	44	2	4	4				5.0
	1987	136	46	119	41	15	1	1			1	0.5
	1988	129	45	145	38	2	1					5.0
	1989	48	24	228	42	12	6					5.0
Galium boreale	1986	60	139	161								0.5
	1987	36	119	197	7	1						5.0
	1988	38	173	149								0.5
	1989	54	228	78								0.5
Lathyrus ochroleucus	1986	13	91	235	19	2						5.0
	1987	35	140	184	1							5.0
	1988	78	231	51								0.5
	1989	174	144	42								0.5
Populus tremuloides (50 - 150 cm)	1986	20	14	117	111	50	36	8	2	2		15.0
	1987	12	6	80	125	81	47	7		2		15.0
	1988	8	8	84	155	74	22	6	1	1	1	15.0
	1989	18	54	192	84	12						15.0
Populus tremuloides (>150 cm)	1986	209	107	42		1		1				0.0
	1987	116	103	132	6	3						0.5
	1988	46	77	185	46	4	1		1			5.0
	1989	30	30	168	102	30						5.0
Populus tremuloides (<50 cm)	1986	29	58	206	54	11	2					5.0
	1987	34	62	247	17							5.0
	1988	20	84	247	7	2						5.0
	1989	24	168	162	6							0.5
Rosa acicularis	1986	11	14	291	42	2						5.0
	1987	14	13	290	41	2						5.0
	1988	4	17	298	41							5.0
	1989			264	96							5.0

Table 4-19 (Cont'd)

Spiraea betulifolia	1986	75	75	201	9		5.0
	1987	61	55	220	23	1	5.0
	1988	61	55	229	15		5.0
	1989	102	66	192			5.0
Viburnum edule	1986	112	65	179	4		5.0
	1987	189	62	108	1		0.0
	1988	169	54	133	4		0.5
	1989	144	78	132	6		0.5

[a]Class frequencies are based on a total of 360 quadrats (1986-88) from 3 replicate blocks of the treatment.
[b]Leading species are those with a median cover of over 1% in at least one year.
[c]16.6% sampling intensity in 1989, values multiplied by 6 for comparison.

Table 4-20. Cover class frequencies[a] by year for leading species[b], low herbicide treatment (2 kg hexazinone/ha)

Species	Year	Cover Class Midpoint												Median
		0	+	5	15	25	35	45	55	65	75	85	95	
Aralia nudicaulis	1986	150	25	148	34	3	0	0	0	0	0	0	0	5.0
	1987	139	14	152	44	10	1	0	0	0	0	0	0	5.0
	1988	139	15	163	36	6	1	0	0	0	0	0	0	5.0
	1989[c]	12	12	252	84	0	0	0	0	0	0	0	0	5.0
Aster ciliolatus	1986	95	54	176	34	1	0	0	0	0	0	0	0	5.0
	1987	160	85	100	13	2	0	0	0	0	0	0	0	0.5
	1988	135	60	145	16	4	0	0	0	0	0	0	0	0.5
	1989	48	48	252	12	0	0	0	0	0	0	0	0	5.0
Aster conspicuus	1986	90	30	198	39	2	0	0	1	0	0	0	0	5.0
	1987	132	64	149	14	1	0	0	0	0	0	0	0	0.5
	1988	116	32	177	30	5	0	0	0	0	0	0	0	5.0
	1989	132	72	156	0	0	0	0	0	0	0	0	0	0.5
Cornus canadensis	1986	73	88	178	17	2	2	0	0	0	0	0	0	5.0
	1987	56	68	201	27	6	2	0	0	0	0	0	0	5.0
	1988	62	34	201	49	11	2	1	0	0	0	0	0	5.0
	1989	12	48	240	60	0	0	0	0	0	0	0	0	5.0
Epilobium angustifolium	1986	50	41	235	28	5	1	0	0	0	0	0	0	5.0
	1987	26	16	264	45	5	3	1	0	0	0	0	0	5.0
	1988	54	14	178	84	24	5	0	1	0	0	0	0	5.0
	1989	36	12	204	96	12	0	0	0	0	0	0	0	5.0
Lathyrus ochroleucus	1986	19	65	258	17	1	0	0	0	0	0	0	0	5.0
	1987	99	89	160	11	1	0	0	0	0	0	0	0	0.5
	1988	157	126	77	0	0	0	0	0	0	0	0	0	0.5
	1989	120	240	0	0	0	0	0	0	0	0	0	0	0.5

Table 4-20 (cont'd)

Populus tremuloides (>150 cm)	1986	240	64	52	3	1	0	0	0	0	0	0	0.0
	1987	127	89	125	13	4	0	1	0	0	0	1	0.5
	1988	121	47	108	57	20	3	0	2	1	1	0	5.0
	1989	0	0	48	108	72	72	60	0	0	0	0	25.0
Populus tremuloides (50-150 cm)	1986	36	17	75	94	76	36	13	7	3	2	1	0	15.0
	1987	37	17	101	100	64	31	7	2	1	0	0	0	15.0
	1988	57	20	96	91	60	26	5	3	1	1	0	0	15.0
	1989	0	0	60	180	96	24	0	0	0	0	0	0	15.0
Populus tremuloides (<50 cm)	1986	33	17	206	80	16	5	2	1	0	0	0	0	5.0
	1987	48	116	171	19	5	1	0	0	0	0	0	0	5.0
	1988	69	105	178	8	0	0	0	0	0	0	0	0	5.0
	1989	12	192	156	0	0	0	0	0	0	0	0	0	0.5
Rosa acicularis	1986	21	15	234	70	16	3	0	1	0	0	0	0	5.0
	1987	23	38	281	17	1	0	0	0	0	0	0	0	5.0
	1988	38	39	250	29	3	1	0	0	0	0	0	0	5.0
	1989	0	24	228	108	0	0	0	0	0	0	0	0	5.0
Viburnum edule	1986	194	38	122	6	0	0	0	0	0	0	0	0	0.0
	1987	122	54	180	3	1	0	0	0	0	0	0	0	5.0
	1988	190	33	132	5	0	0	0	0	0	0	0	0	0.0
	1989	48	24	288	0	0	0	0	0	0	0	0	0	5.0

[a]Class frequencies are based on a total of 360 quadrats (1986-88) from 3 replicate blocks of the treatment.
[b]Leading species are those with a median cover of over 1% in at least one year.
[c]16.6% sampling intensity in 1989, values multiplied by 6 for comparison.

Table 4-21. Cover class frequencies by year for leading species, high herbicide treatment (4 kg hexazinone/ha)

Species	Year	Cover Class Midpoint											Median
		0	+	5	15	25	35	45	55	65	75	85	
Aralia nudicaulis	1986	160	45	138	13	4	0	0	0	0	0	0	0.5
	1987	145	38	162	14	1	0	0	0	0	0	0	0.5
	1988	202	27	114	16	1	0	0	0	0	0	0	0.0
	1989[b]	136	24	172	20	8	0	0	0	0	0	0	5.0
Aster ciliolatus	1986	59	59	207	31	3	1	0	0	0	0	0	5.0
	1987	244	92	24	0	0	0	0	0	0	0	0	0.0
	1988	129	112	115	3	1	0	0	0	0	0	0	0.5
	1989	56	100	200	4	0	0	0	0	0	0	0	5.0
Aster conspicuus	1986	82	30	204	43	1	0	0	0	0	0	0	5.0
	1987	162	122	75	1	0	0	0	0	0	0	0	0.5
	1988	113	67	165	14	1	0	0	0	0	0	0	0.5
	1989	88	104	164	4	0	0	0	0	0	0	0	0.5
Cornus canadensis	1986	84	138	134	4	0	0	0	0	0	0	0	0.5
	1987	65	79	189	27	0	0	0	0	0	0	0	5.0
	1988	59	66	197	31	5	2	0	0	0	0	0	5.0
	1989	84	52	180	32	8	0	4	0	0	0	0	5.0
Epilobium angustifolium	1986	49	39	246	26	0	0	0	0	0	0	0	5.0
	1987	106	32	168	45	7	0	2	0	0	0	0	5.0
	1988	80	28	142	85	21	3	1	0	0	0	0	5.0
	1989	48	24	184	96	8	0	0	0	0	0	0	5.0
Galium boreale	1986	55	163	140	2	0	0	0	0	0	0	0	0.5
	1987	102	193	61	3	1	0	0	0	0	0	0	0.5
	1988	71	91	170	20	8	0	0	0	0	0	0	5.0
	1989	56	92	184	28	0	0	0	0	0	0	0	5.0

Table 4-21 (cont'd)

Lathyrus ochroleucus	1986	25	108	209	18	0	0	0	0	0	0	0	5.0
	1987	183	132	44	1	0	0	0	0	0	0	0	0.0
	1988	285	73	2	0	0	0	0	0	0	0	0	0.0
	1989	276	84	0	0	0	0	0	0	0	0	0	0.0
Populus tremuloides (>150 cm)	1986	237	64	58	1	0	0	0	0	0	0	0	0.0
	1987	169	93	87	7	4	0	0	0	0	0	0	0.5
	1988	200	83	64	10	2	0	1	0	0	0	0	0.0
	1989	120	76	112	24	28	0	0	0	0	0	0	0.5
Populus tremuloides (50 - 150 cm)	1986	34	30	101	87	68	17	10	7	2	3	1	15.0
	1987	29	73	190	42	18	7	1	0	0	0	0	5.0
	1988	61	57	141	54	29	12	2	3	1	0	0	5.0
	1989	40	28	144	92	36	8	8	0	4	0	0	5.0
Populus tremuloides (>50 cm)	1986	36	18	222	69	12	2	0	1	0	0	0	5.0
	1987	44	214	100	2	0	0	0	0	0	0	0	0.5
	1988	67	128	157	8	0	0	0	0	0	0	0	0.5
	1989	48	148	160	4	0	0	0	0	0	0	0	0.5
Rosa acicularis	1986	22	9	259	60	9	1	0	0	0	0	0	5.0
	1987	49	189	119	3	0	0	0	0	0	0	0	0.5
	1988	60	87	203	9	1	0	0	0	0	0	0	5.0
	1989	116	68	152	24	0	0	0	0	0	0	0	0.5
Spiraea betulifolia	1986	124	45	183	8	0	0	0	0	0	0	0	5.0
	1987	191	165	4	0	0	0	0	0	0	0	0	0.0
	1988	268	78	14	0	0	0	0	0	0	0	0	0.0
	1989	296	52	12	0	0	0	0	0	0	0	0	0.0

[a]Leading species are those with a median cover of over 1% in at least one year.

[b]25% sampling intensity in 1989, values multiplied by 4 for comparison.

Table 4-22. Frequency of quadrat changes of two or more cover classes for species with a median cover class of 5% or more in one of three years (360 quadrats/year) in one or more of the treatments

	1986-1987				1987-1988				1986-1988			
	DOWN	UP	NC	ZERO	DOWN	UP	NC	ZERO	DOWN	UP	NC	ZERO
High herbicide (4 kg hexazinone/ha)												
Aralia nudicaulis	3	0	222	135	0	1	232	127	2	1	229	128
Aster ciliolatus	30	0	282	48	0	4	274	82	13	0	317	30
Aster conspicuus	25	0	267	68	0	3	264	93	7	1	288	64
Calamagrostis canadensis	31	0	240	135	0	0	80	280	31	0	241	88
Cornus canadensis	0	2	299	59	0	8	309	43	0	11	303	46
Epilobium angustifolium	5	9	313	33	3	27	277	53	2	42	288	28
Fragaria virginiana	19	0	176	89	0	0	17	343	19	0	176	165
Galium boreale	0	1	320	39	0	11	306	43	0	11	321	28
Lathyrus ochroleucus	16	1	324	19	1	0	198	161	16	0	323	21
Populus tremuloides	92	0	246	22	2	24	320	14	83	11	253	13
Populus tremuloides	0	9	186	165	2	7	235	116	0	14	215	131
Rosa acicularis	60	0	279	21	0	0	338	22	37	0	304	19
Spiraea betulifolia	33	0	320	7	0	0	339	21	28	0	320	12
Viburnum edule	7	0	246	107	0	0	191	169	7	0	237	116
Total medium shrubs (50-150 cm)	98	0	250	12	1	28	318	13	91	18	242	9
Total tall shrubs (>150 cm)	0	3	191	166	0	7	235	118	0	13	217	130
Total forbs	278	1	81	0	3	201	156	0	152	28	180	0
Total graminoides	47	0	305	8	0	0	288	72	40	0	315	5
Total mosses and bryophytes	10	12	297	41	14	24	286	36	13	18	295	34
	1	0	191	165	0	0	208	152	0	0	209	151
Low herbicide (2 kg hexazinone/ha)												
Aralia nudicaulis	17	15	211	117	23	31	194	112	11	35	200	114
Aster ciliolatus	11	38	280	31	7	37	245	71	10	33	286	31
A. conspicuus	33	8	289	30	11	13	301	35	31	10	303	16
Calamagrostis canadensis	56	0	250	54	0	1	181	178	50	0	257	53
Cornus canadensis	8	4	314	34	22	15	286	37	4	15	304	37
Epilobium angustifolium	17	18	303	22	29	23	286	22	16	26	299	19
Fragaria virginiana	15	0	187	158	0	0	43	317	15	0	183	162
Galium boreale	0	0	284	76	0	5	273	82	0	1	282	77
Lathyrus ochroleucus	1	15	331	13	1	104	219	36	3	43	301	13
Populus tremuloides	197	1	142	20	147	0	176	37	209	0	126	25

Table 4-22 (cont)

Populus tremuloides	0	156	163	41	2	132	178	48	0	171	138	51
Populus tremuloides	59	5	271	25	4	57	270	29	43	18	275	24
Rosa acicularis	47	1	304	8	2	2	347	9	41	1	311	7
Spiraea betulifolia	17	0	228	115	0	1	212	147	7	1	234	118
Viburnum edule	198	1	138	23	147	1	174	38	199	1	137	23
Total medium shrubs (50-150 cm)	0	172	145	43	5	138	187	30	2	179	146	33
Total tall shrubs (>150 cm)	346	1	13	0	303	3	53	1	345	0	15	0
Total forbs	23	266	71	0	0	339	19	2	11	295	54	0
Total graminoides	100	0	238	22	69	0	260	31	98	0	242	20
Total mosses and bryophytes	0	2	333	25	2	20	305	33	1	22	304	33
Control 5												
Aralia nudicaulis	1	0	250	109	0	0	255	105	1	1	254	104
Aster ciliolatus	4	20	275	61	21	0	302	37	8	1	312	39
Aster conspicuus	4	1	339	16	2	1	346	11	5	0	341	14
Calamagrostis canadensis	6	2	329	23	14	2	326	18	14	2	323	21
Cornus canadensis	0	1	304	55	2	0	309	49	0	1	304	55
Epilobium angustifolium	0	3	342	15	3	0	342	15	2	0	346	12
Fragaria virginiana	3	5	238	114	10	0	239	111	5	3	247	105
Galium boreale	0	1	331	28	1	0	334	25	0	0	333	27
Lathyrus ochroleucus	3	0	355	2	1	0	343	16	12	0	341	7
Populus tremuloides	19	26	305	10	31	11	312	6	28	19	307	6
Populus tremuloides	1	3	250	106	1	17	298	44	0	35	280	45
Populus tremuloides	20	0	328	12	2	1	348	9	28	0	323	9
Rosa acicularis	3	2	354	1	1	3	355	1	5	1	354	0
Spiraea betulifolia	0	0	313	47	1	2	307	50	1	0	311	48
Viburnum edule	0	0	196	164	0	1	202	157	0	0	204	156
Total medium shrubs (50-150 cm)	30	34	294	2	25	31	304	0	25	45	290	0
Total tall shrubs (>150 cm)	7	3	250	100	0	14	309	37	5	30	291	34
Total forbs	49	90	221	0	157	19	184	0	136	56	168	0
Total graminoides	18	3	338	1	13	2	345	0	27	2	331	0
Total mosses and bryophytes	15	30	311	4	44	18	288	10	23	21	308	8

Down - decrease of 2+ cover classes
UP - increase of 2+ cover classes
NC - no change of more than one cover class, but are present in at least one of two years
Zero - absent in both years

period. Most changes occurred in 1987-1988. The changes in cover of leading species were similar to changes in total cover values by strata in control plots.

The low concentration of hexazinone did not reduce but in some cases increased the cover as in *Aralia nudicaulis, Cornus canadensis, Epilobium angustifolium, Populus tremuloides* (50-150 cm and >150 cm), and *Rosa acicularis*. The treatment resulted in a partial control of *Aster ciliolatus, A. conspicuus, Lathyrus ochroleucus, Calamagrostis canadeansis*, and *Populus tremuloides* (<50 cm) over two to three growing seasons. These species analyses are consistent with the changes in total cover of forbs and shrubs (Tables 4-14 to 4-16; Figs. 4-12 to 4-16; and Figs. 17-15 in Appendix-B). There was either no change or an increase in *Cornus canadensis, Epilobium angustifolium*, and *Galium boreale*. The qualitative response for leading species based on each sample quadrat is summarized in Table 4-22. The results confirm the response of vegetation that had already entered the recovery phase from the impacts of herbicide and mechanical treatments. The forbs were more abundant in LH than in HH plots while medium shrubs, graminoids and mosses were more abundant in HH than in LH plots. Considering the substrate types, trenches appeared to be best and berms poorest for medium shrub and forb cover. Intertrench areas were best and berms poorest for graminoids and the reverse for mosses and bryophytes. Considering the performance of the leading species (those present in at least 50% of quadrats) in relation to herbicide application rate and substrate type, *Aralia nudicaulis, Calamagrostis canadensis*, and *Galium boreale* were more abundant in DT+LH plots than in the DT+HH plots whereas the opposite was true for *Aster ciliolatus, A. conspicuus, Epilobium angustifolium, Rosa acicularis*, and *Populus tremuloides*. Trenches were generally best and berms poorest for *Epilobium angustifolium, Populus tremuloides, Rosa acicularis*, and *Viburnum edule*, and intertrench areas were best and berms poorest for *Aralia nudicaulis* and *Aster conspicuus* in terms of changes in cover class frequencies by substrate types for leading species (Table 4-23).

The application of hexazinone at 4 kg/ha effectively controlled total vegetation cover. The leading species were most impacted for two growing seasons following the fall herbicide application (*Aralia nudicaulis, Aster ciliolatus, A. conspicuus, Lathyrus ochroleucus, Populus tremuloides, Rosa acicularis* and *Spiraea betulifolia*). Cover of species such as *Cornus canadensis, Epilobium angustifolium*, and *Galium boreale* either did not change or increased as a result of the treatment.

The results of the limited number of samples for species cover collected for plots treated mechanically alone or in combination with hexazinone are summarized in Table 4-23. The plots included double-disked (DD), disk-trenched plus 2 kg hexazinone/ha (LH-DT) or 4 kg/ha (HH-DT). Cover of leading species was observed on four substrate types created by mechanical treatments (trench, berm, intertrench, and double-disked surface). In 1989 *Calamagrostis canadensis* and *Galium boreale* were prevalent on all substrates except DD. *Aster ciliolatus* did not show any preference for a particular substrate type. It appears from a limited amount of data that trenching and low herbicide and their combination favor the competing species after three seasons following the treatments and therefore may be unsuitable treatments for enhancing crop seedling growth. On the other hand, berms are the best sites for crop seedlings and poorest for competing species in mechanically treated plots.

c) Changes in species complexes

In (a) and (b) above, changes in vegetation have been presented by vegetation strata and individual leading species. The changes in vegetation structure as a species complex in herbicide-treated and control plots is the subject of a M.Sc. Thesis in preparation by M.D. Fairbarns. The following highlights trends in vegetation change determined by his study.

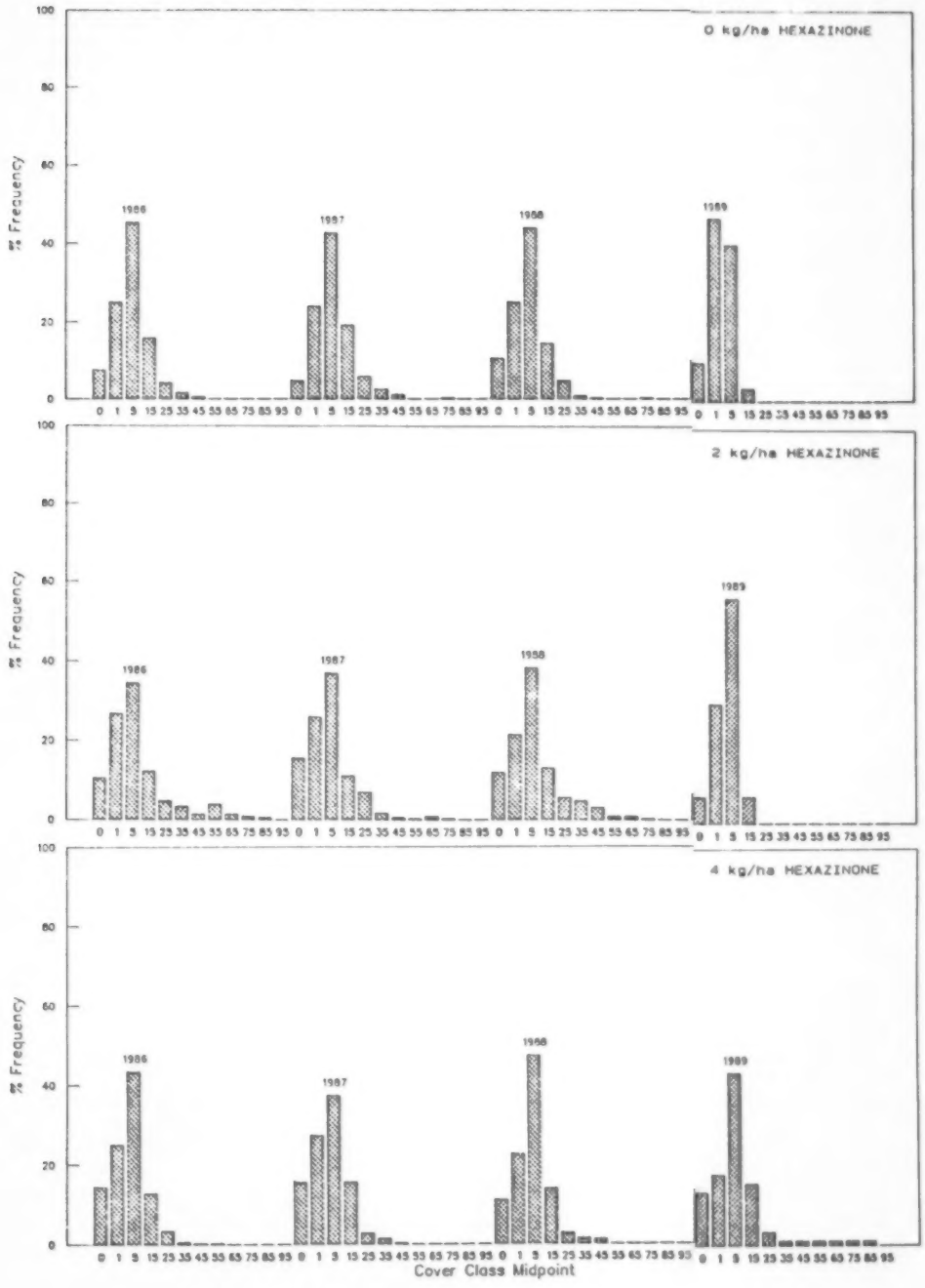

Figure 4-16. Percent frequency of cover classes (1986-1989) for mosses in control and hexazinone-treated (as PRONONE 10G) plots.

Table 4-23. Cover Class Frequencies by Substrate Type for Leading Species in Mechanically Treated Plots (Method II), 1989

Species	Treatment	Cover Class Midpoint (%) 0				0.5				5				15				25				35			
		T	B	I	D	T	B	I	D	T	B	I	D	T	B	I	D	T	B	I	D	T	B	I	D
ARANUD	Low							1		5	8	7		3											
	High	1	2	1						6	5	4		1	1	3									
	DD				1				1				5				1								
ASTCIL	Low	2				3	4	2		3	4	5				1									
	High	1		1		2	2	3		4	4	3		1	2	1									
	DD				1				1				5				1								
ASTCON	Low	1	3	1		5	4	3		2	1	4													
	High		1			2	2	1		4	3	6		2	2	1									
	DD				4								3				1								
CORCAN	Low		1			1	2			4	4	4		2	1	3									
	High	3	3			3	3	2		2	2	5				1									
	DD				3				3				2												
EPIANG	Low	1	3	3		1	1	1		2	4	3		4		1									
	High		2	1						3	4	4		4	1	3		1	1						
	DD				1				1				1				5								
GALBOR	Low	1	3			4	3			2	2	6		1		2									
	High	1	2			4	3	4		3	3	4													
	DD				5				1				2												
POPTRE	Low	4	6	5			1	1		3	1			1		2									
(50-150 cm)	High		2			1	2			3	3	2		2	1	3		2		2				1	
	DD				4				3				1												
POPTRE	Low	2	3	3		1	2			5	3	5													
(< 50 cm)	High		2			5	1	4		3	5	4													
	DD				2				1				4				1								
ROSACI	Low	2	3	2			1			5	4	6		1											
	High			2			1	1		4	4	4		4	3	1									
	DD				2				6																
SYMALB	Low	3	3	2		1	1			1	4	6		3											
	High	1	5	4		2		3		5	2	1			1										
	DD				6			2																	
VIBEDU	Low	1	4	2		2		1		5	4	5													
	High	2	4	1		2	1	1		4	3	6													
	DD				7				1																
TOTAL	Low	4	5	5		1	2	1		2	1		1		2										
shrubs	High		2			1	2			3	3	3		1	1	1		3		3				1	
	DD				4				3				1												
TOTAL	Low														1				3	1			4	1	
forbs	High														1			2	3	1		3	2	3	
	DD																1				3				3
TOTAL	Low	1	4	1		7	4	6				1													
graninoids	High	1	1			5	5	5		1	1	3		1	1										
	DD								1				5				1				1				
TOTAL	Low		1			2				5	7	7		1		1									
mosses &	High							1		8	2	3			3	4							3		
Bryophytes	DD								2				3								1				1

T - trench; B - berm; I - inter-trench area; D - double-disked surface, Leading species are those present in at least 50% of the quadrats.
LOW - low herbicide + mechanical treatment combinations.
HIGH - high herbicide + mechanical treatment combinations.
DD - double-disked treatment.

Table 4-23. (Cont'd)

Species	Treatment	Cover Class Midpoint (%) 45 T	B	I	55 D	T	B	I	65 D	T	B	I	75 D	T	B	I	85 D	T	B	I	D
ARANUD	Low																				
	High																				
	DD																				
ASTCIL	Low																				
	High																				
	DD																				
ASTCON	Low																				
	High																				
	DD																				
CORCAN	Low	1	1																		
	High																				
	DD																				
EPIANG	Low																				
	High																				
	DD																				
GALBOR	Low																				
	High																				
	DD																				
POPTRE (50-150 cm)	Low																				
	High																				
	DD																				
POPTRE (< 50 cm)	Low																				
	High																				
	DD																				
ROSACI	Low																				
	High																				
	DD																				
SYMALB	Low																				
	High																				
	DD																				
VIBEDU	Low								1												
	High																				
	DD																				
TOTAL shrubs (50-150 cm)	Low																				
	High																				
	DD																				
TOTAL forbs (graminoids)	Low	5			1				3				4								1
	High	1	1		2				1				2				1	1			
	DD					1															
TOTAL mosses & bryophytes	Low																				
	High																				
	DD																				
TOTALMN	Low																				
	High																				
	DD																				

T - trench; B - berm; I - inter-trench area; D - double-disked surface. Leading species are those present in at least 50% of the quadrats.
LOW - low herbicide + mechanical treatment combinations.
HIGH - high herbicide + mechanical treatment combinations.
DD - double-disked treatment.

Vegetation composition in the control (0 kg/ha), low (2 kg/ha), and high (4 kg/ha) treatment plots of Blocks 1 and 2 in 1986, 1987, 1988, and 1989 was determined by pooling species cover data from the quadrats. (No 1989 data was available for vegetation in the low herbicide treatment plot of Block 1.) The relative similarity of vegetation data sets from different treatments in different years was determined using DCA, detrended correspondence analysis (Hill 1979), and the results are illustrated in Fig. 4-16. Data from Blocks 1 and 2 were analyzed separately to prevent block differences from confounding the effects of treatment and time. Gradients of differences in species proportions were derived (axes or eigenvectors), and the proportion of the vegetation variability expressed by each was calculated (eigenvalues). In both analyses, the first twoeigenvalues were much higher than the third and fourth, indicating that most of the observed differences in vegetation composition were represented in the simple two-dimensional plots provided in Fig. 4-17.

In both blocks, differences in pretreatment (1986) vegetation were slight compared with vegetation changes occurring in later years.

Vegetation responded similarly whether treated at the 2 or 4 kg/ha dosage. Initially, the vegetation shifted laterally along axis 1 (the most pronounced gradient of vegetation composition among treatment plots over time). The strong initial shift was expected and reflect a general decrease in the abundance of most species as a result of the herbicide application. Species subsequently could have recovered toward their pretreatment proportions, assumed a new equilibrium, or continued to diverge from their initial composition. In both the high and low treatments, the vegetation continued to diverge from its pretreatment composition indicating that there was no recovery toward the initial species proportions, nor had a new equilibrium developed.

The control plots also responded similarly in both blocks. Their vegetation changed little along axis 1 but shifted farther up along axis 2 in each successive year. The constant upward shift indicated a steadily changing composition reflecting plant succession rather than a dynamic equilibrium. The succession was probably a combination of the effects of a closing aspen canopy and the residual effect of slow readjustments to the conditions created by timber harvesting in 1982.

The treated plots also showed some upward movement along axis 2, though it was much weaker than that which occurred in the treatment plots. This indicated that at least some aspects of the successional changes occurring in the control plots prevailed despite herbicide treatment.

In conclusion, both the control and treated plots were in dynamic, nonequilibrium states. In the control plots, the multispecies changes probably represented a vegetation response to canopy infilling. In the treated plots the changes reflected the immediate disturbance resulting from herbicide damage and the instability of the consequent species mixture. The treated plots neither reverted to their initial composition nor converged along a new path with the vegetation of untreated controls.

4.5 CONCLUSIONS

The primary objective of the vegetation management project was to evaluate several methods to reduce the vegetation competition with the crop species to enhance its growth to a free-to-grow stage. Chemical and mechanical methods were employed either at the preplanting phase as site preparation or at the postplanting crop release phase of the management of a mixedwood forest dominated by *Populus tremuloides* regrowth. One of the objectives of the environmental component of the study was to evaluate the impact of silvicultural methods on the composition, structure, and dynamics of vegetation excluding the crop tree performance. The major difficulties in these

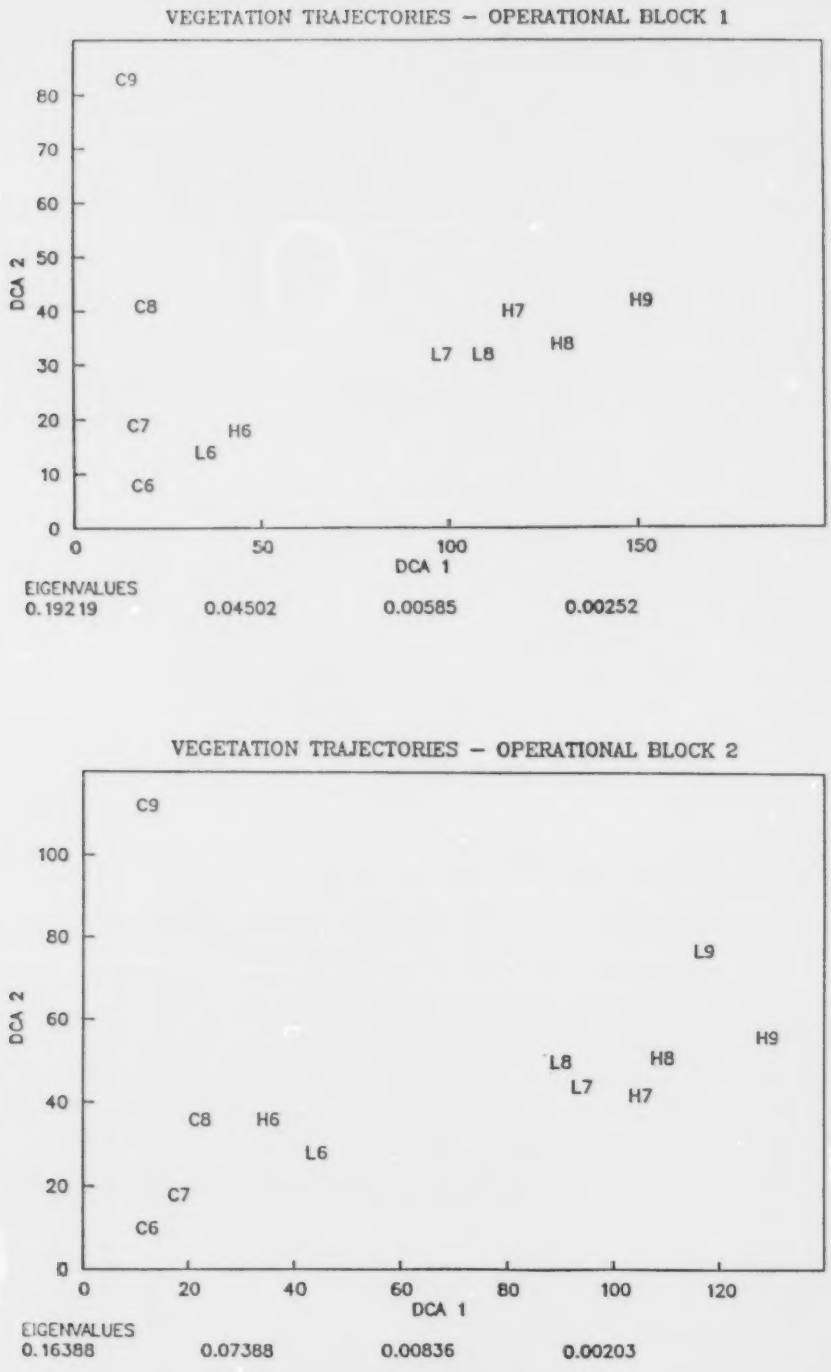

Figure 4-17. Vegetation trajectories in blocks 1 and 2 of the operational application. Letters refer to treatment (C=0 kg/ha; L=2 kg/ha; H=4 kg/hs). Numbers refer to the year of observation (6=pre-treatment data from 1986; 7=1987; 8=1988; 9=1989). Eigenvalues reflect the amount of vegetation variation explained by successive DCA axes (only axes 1 and 2 graphed).

assessments has been to deal with the highly variable vegetation. The variation was high among the plot densities of target species among blocks, treatment plots within blocks, and sampling subplots and quadrats within treatment plots. The variability was as great for cover. Superimposed on this inherent variability was the heterogeneity of the distribution of the intensity of mechanical treatments and the amount and distribution of chemical treatments in sampling units within treatment plots. In spite of the above limitations, several conclusions for the present and directions for the future have been drawn based on a large data base developed from the Grande Prairie study.

1) Pretreatment surveys of vegetation indicate that in some years up to 20% of the foliage can be damaged by insect and disease agents in *Populus tremuloides*. The effects of natural pests should be assessed in control and prospective treatment areas before impacts of vegetation management methods are evaluated. The biologicalcontrol agents of target species should be surveyed in future for their potential to control target species in relation to the degree and duration of control required to enhance growth of the crop species.

2) Fall application of 2- and 4-kg hexazinone did not produce any distinct visible effects in the year of application. The herbicide took effect in the growing season following the year of application. The herbicide at the low rate was not effective in producing the desired control of vegetation.

3) As a result of PRONONE 10G application, phenological disruptions in the affected species will occur during the 2 years following application.

4) Pretreatment stem density of woody species in different blocks and treatment plots of the same block was highly variable (42,520 to 92,788 stems/ha). Over 70% of these were aspen (*Populus tremuloides*) stems. The mechanical, PRONONE 10G, and their combination resulted in varying degrees of control of stem density. Low herbicide (2 kg hexazinone/ha) resulted in a net gain of woody stems. LH-DT, HH-DD, and DD resulted in 40, 50, and over 90% control of woody stems by 1989. Most control occurred during the first 2 years following treatments. By 1989 most species resumed normal growth (Fig. 4-18 and 4-19).

   The herbicide effects were maximal by the second growing season following the application. Species differed in their sensitivity to hexazinone. Of the two target species, *Calamagrostis canadensis* was highly sensitive and *Populus tremuloides* sensitive. At the higher rate (4 kg/ha) of hexazinone, most woody and herbaceous species produced typical chlorosis and necrosis followed by defoliation except *Corylus, Alnus*, and *Betula* which exhibited no herbicide damage symptoms. Foliar damage by insects and diseases was of much lower severity as compared with the damage by the herbicide. All species exhibited no visible symptoms of herbicide damage on the 1989 growth (Figs. 4-18 and 4-19). In future trials for use of PRONONE 10G, a 2 kg hexazinone/ha rate is not recommended for fall application. Based on the visible symptoms and defoliation, maximum impacts in the form of herbicide residues in vegetation and changes in nutrient levels and dynamics are expected during the two growing seasons following application.

5) Selection of the method of control would depend on the gains in crop seedling growth. Although the double-disking treatment resulted in total control of woody stems, its use is questionable because of total loss of vegetation structure and species diversity over a period of 2 years and complete replacement of the competing grass cover during the 3rd year. In addition there is complete loss of soil integrity through displacement of soil horizons rich in nutrient and organic matter. In comparison the disk-trenching resulted in 20-60% soil surface disturbance. Less than 20% of the terrain was disturbed in control as well as herbicide- treated areas by the harvesting process.

6) During heavy rains, soil erosion and off-site movement of soil from disturbed surfaces was observed to be significant in disk-trenched areas. It is recommended that if disk-trenching is to be the selected method of vegetation management, trenches should be laid out parallel to the contours of the slopes. Before decisions are made as to the preferred method of vegetation control, there is need to establish the optimum levels of density control to enhance the seedling growth to a desired level.

7) Vegetation and seedling performance should be sampled on site-preparation and crop-release plots for the 5th and 8th years after the treatment application in 1991-92 and 1994-95 (site-preparation plots) and in 1990/91, 1993/94, and 1996/97 (crop-release plots).

8) Control of aspen and non-aspen woody stems should also be evaluated for wildlife implications.

9) Over 110 plant species occurred in the study area. The PRONONE 10G application resulted in an increase in species richness. There was no loss of species observed as a result of the vegetation management by disk-trenching and the herbicide.

10 Changes in vegetation cover in the shrub stratum were consistent with changes in the woody stem density. In controls, maximum changes in vegetation cover occurred from 1987 to 1988 in the tall shrub, forb, and graminoid strata. The LH application (2 kg hexazinone/ha) had no overall measurable effect on the cover of medium shrub, forb, and moss strata. It resulted in a decrease of graminoids by 10% and an increase of tall shrubs by 20%. The only effective control of vegetation by PRONONE 10G was at the 4 kg ai/ha rate over two growin seasons.

A recovery process began in 1989 during the third growing season following the treatment (Fig. 4-17 and 4-18). The effectiveness of vegetation control in mechanically (alone or in combination with herbicide) treated plots was in the order DD > HH-DT > LH-DT > DT. The selection of any of these methods should include an assessment of terrain disturbance, level of reduction in cover required for optimum crop seedling growth, soil erosion, and cost-benefit analysis. Fifth and eighth year data on crop seedling growth will be required for such assessments.

11) The changes in number of species, total cover and cover of individual species, and stem density peaked after two growing seasons following the treatments. The vegetation cover recovered towards the pretreatment levels in 1989 (Figs. 4-19 and 4-19). However, the changes in relative composition and cover on the herbicide-impacted areas are still evident in terms of community structure and dynamics expressed in changes in successional trends. The direction and duration of this process should be determined by sampling in the 5th and 8th post-treatment years. Similar information on the mechanically treated plots is lacking because of the difficulty of establishment and location of permanent plots after the application of mechanical treatments.

Figure 4-18. General conditions of the vegetation in site-treatment plots. A. Vegetation in July 1989 in a control plot. Notice the dense woody overstory of Populus tremuloides and herbaceous stratum of forbs and Calamagrostis canadensis **B, C.** Vegetation in July 1989 in a plot treated with 2 kg hexazinone/ha in August 1986. **D.** Vegetation in July 1989 in plot treated with 4 kg hexazinone/ha. Notice the standing dead stems, and moderate cover of aspen and forbs.

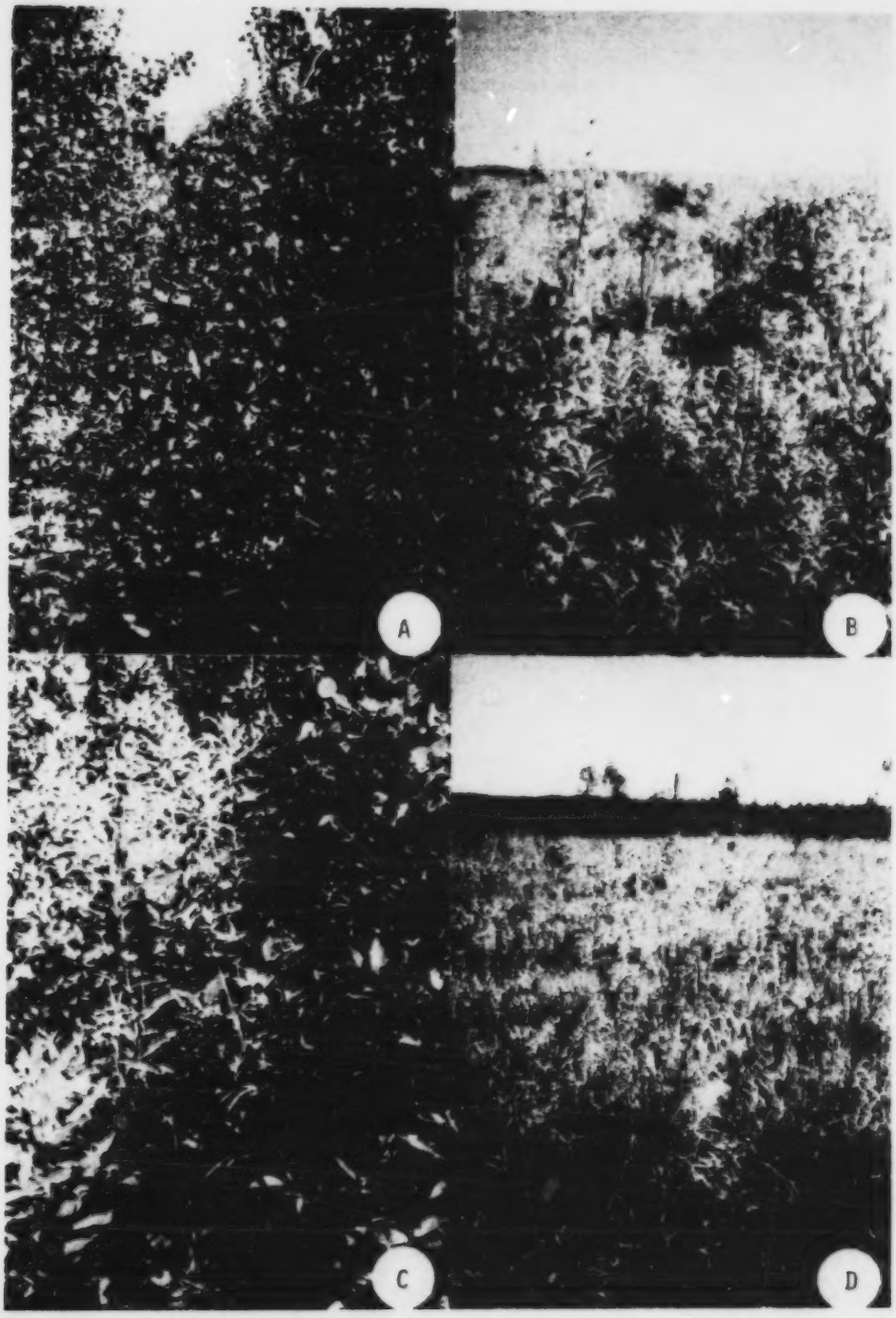

Figure 4-18 General conditions of the vegetation in site-treatment plots. A, C. 1989 vegetation in a plot treated with 2 kg hexazinone/ha in August 1986 plus disk-trenching in May 1987. **B.** Vegetation in July 1989 in a plot treated with 4 kg hexazinone/ha in August 1986 plus disk-trenching in May 1987. Notice the dead woody stems and dominance of Epilobium angustifolium in the forb layer. **D.** Vegetation in July 1989 in a double-disked plot treated in May 1987. Notice the dense cover of grasses and gradual aspen regrowth.

Section 5

DEVELOPMENT OF APPLICATION, SAMPLING, AND ANALYTICAL TECHNOLOGIES

Results of seven separate studies on the development of application, sampling, and analytical technologies are reported, including 1) application of granular herbicide by one aerial (helicopter-attached) and two ground (truck-mounted) applicators, 2) application of liquid herbicide by a logarithmic sprayer, 3) sampling method for herbicide residues in forest soils immediately following application, and 4) analytical methods for determination of hexazinone residues in soil and vegetation samples.

5.1 DETERMINATION OF GRANULE DISTRIBUTION FROM AERIAL AND GROUND APPLICATION[6]

5.1.1 Background

Aerial applications of liquid formulations of herbicides result in off-target drift, require sophisticated delivery systems, and are weather dependent (air temperature, humidity, and wind velocity) (Feng and Feng 1988b; Payne et al. 1987; Yates et al. 1985). The use of granular formulations may greatly reduce concerns on the off-target drift and remove weather dependency (Lowery 1984). Application equipment used for granular herbicides includes hand seeders, backpack units, skidder- or tractor-mounted units, and helicopters carrying seeders or fertilizer buckets[7].

A new granular formulation of hexazinone designed to control the off-target drift during aerial application has been submitted for registration in Canada for forestry use (Feng, Stornes, and Rogers 1988). In this formulation, granules are of irregular size and shape and vary greatly. The granules have a hard insoluble clay base and are surface-coated with two layers: a 10% (ai) hexazinone layer and an inactive protective coating. The protective coating minimizes dust formation and loss of hexazinone during shipping, handling, and dispersal (Feng, Feng, and Sidhu 1989).

For a given weight, smaller granules would result in greater numbers with large total surface area delivering a larger amount of hexazinone to the target. The size differences could cause different distribution patterns of small and large granules after application and, therefore, could change the amount of granule surface exposure to rain (Feng, Feng, and Sidhu 1989). The distribution and release of hexazinone over an application swath may be related directly to the weight-class frequency of granules (Lowery 1984).

To apply this granular hexazinone, Weidenfeller (1985) tested four different types of ground and aerial dispersal systems, including a hand seeder, a backpack mist blower, a commercial ground spreader, and a helicopter equipped with granular seeders. The commercial ground spreader with electronic flow units and the helicopter using granular seeders were the most accurate and successful

---

[6]Feng and Sidhu (1989).

[7] Johnson, S. A. 1987. Pronone herbicide: a granular hexazinone formulation for site preparation and conifer release. Speech presented at 9th For. Veg. Manage. Conf., Redding, Calif. The script may be obtained from Wilbur-Ellis, 212 Industrial Dr., Stockton, CA 95206.

granule applicators and were superior to the mist blower and the hand seeder. Cochran and Boring[8] reported an improved uniformity of granule distribution in aerial applications after modifying a seeder and a fertilizer bucket.

No data has been published on the physical characteristics of the granular formulation or its distribution pattern during aerial and ground application. This paper reports the results of a study on the variation of granule size in a blank hexazinone formulation and on the distribution patterns of granules applied from a truck-mounted pellet applicator and from a bucket spreader attached to a helicopter.

5.1.2 Materials and Methods

A blank granular formulation[9] was used for the granule-size variation tests and for the ground and aerial application tests. The granules of the blank formulation were without hexazinone but were surface coated with the protective layer. The blank granular formulation was used for size-variation tests. The manufacturing of the blanks was similar to that of the commercial formulation. The weight of granules of the blank formulation is 90% of that in a commercial formulation (with 10% w/w hexazinone). A total of 315 granules were sampled randomly from a 10-kg lot of the blank formulation and were weighed individually. The mean granule weight and coefficient of variation (% CV), weight range, median, and max.:min. ratio were calculated. The samples were allotted to weight classes with 5-mg intervals, and the percent weight-class frequencies of granules were calculated.

5.1.2.1 Ground applicator tests

A rotary pellet applicator[10] was mounted on a 3-ton truck. The pellet applicator consisted of two independent storage compartments, transfer systems, and hydraulic delivery arms on both sides of the machine. Each side had an independent automatic control with a flow monitor that delivered a nominal 5-70 kg/ha. The pellets were moved from the metering box to an airlock, that blew the pellets to a spinner which, depending on its rotation speed,would spread the pellets from 6 to 12 m. The delivery arms were located at the front of the truck and were adjustable within 90 degrees from the front to the side. The arms were computer-controlled and self-adjusting for height to follow ground surface variations. The machine was tested at Nisku, Alberta, about 30 km south of Edmonton. A 30- by 12-m test plot was established on level ground. Four 12-m wide transects were laid at 5, 10, 20, and 25 m. Grass was mown to 3 cm high. The truck travelled at 2-2.5 km/h in one direction along the right-hand side of the plot. The arm was set at a 15-degree angle from the front. The spinner was 4 m above ground level. Only one side of the spreader was used for granule application, and the target swath width was 5 m between 2.5 and 7.5 m from the truck path. This design of treatment plot width and distance from the granule spreader allowed room in an operational

---

[8] Cochran, R. J., and L. E. Boring. 1988. Aerial application of a granular herbicide. Pro-Serve Inc., 400 E. Brooks Rd., Memphis, TN.

[9] Supplied by the Canadian dealer for PRONONE 10G: Pfizer C & G Inc., 1 Wilton Grove Rd., London, Ontario N6A 4C6. (The dealership was transferred to United Agriproducts at the same address in August 1988.)

[10] ACE Rotary Pellet Applicator: Ace Vegetation Control Service Ltd., 1426 Meridian Rd. N.E., Calgary, Alberta T2A 2N9.

setting for a truck traveling on a 5-m wide buffer to treat a 5-m wide strip of vegetation for conifer release and preplanting site preparation. Nine 8.5-cm deep wooden trays (0.5 by 0.5 m) lined with plastic sheeting were placed end to end within this 5-m section on each transect to catch granules. Three additional collectors were placed at 0, 10, and 12 m on each transect. A 1-m long railroad tie (15 by 15 cm) was placed at 21 m on the left-hand track of the truck path to simulate an uneven surface in the forest. The effect of a bump to the granule distribution was examined at Transect 4 at 25 m. Granules were applied at nominal 20 and 40 kg/ha rates and application was repeated twice after the initial calculation by using granule discharge rate, target swath width, and truck traveling speed. Granules collected in individual trays were weighed to determine deposition rates at different distances. The mean rates and standard errors for each distance and treatment were calculated. Also, individual granules from each tray were weighed and were allotted to weight classes with 5-mg intervals. Percent weight-class frequencies were calculated in relation to the distances and treatments.

5.1.2.2 Aerial applicator tests

These tests used an applicator-spreader[11] attached to a Bell-206 helicopter. The spreader weighed 90 kg and had a 1.3-m^3 capacity. The bucket spreader was a light-weight, high-strength fiberglass and was equipped with an antirotational device for stability. The metering gate was air-operated by a self-contained battery with fine adjustment and quick closure and was controlled from the helicopter's cockpit. The spreader was capable of a 0.2-100 kg/min flow rate and a 30- to 60-m effective swath related to the flight elevation.

The study site for aerial applicator tests was at Grande Prairie, Alberta, about 450 km northwest of Edmonton. A 100-m flight path (one direction) was marked with three flags on level ground (6 ha). Grass was mown to 3 cm high. Two 40-m long transects, perpendicular to and centered on the flight path, were placed at 25 and 75 m. Forty-one polyethylene collection trays (40.5 cm long by 27 cm wide by 10 cm deep), comprising a total surface of 4.5 m^2 were placed along each transect and were centered lengthwise at each 1-m spacing. The distance between trays on the transect was 59.5 cm. The bottom of each tray was lined with a sheet of laboratory bench liner[12] to reduce the force of granule impact and to minimize the possibility of granules bouncing out of the collection tray. Granules collected from each tray were weighed separately.

The aerial applicator delivery rate was calibrated at 20 kg/ha. A single application run was used to test the 20 kg/ha nominal deposition rate, and a double application run on the same swath was used for the 40 kg/ha rate. Each test was repeated once. The helicopter flew at 72 km/h in one direction at a 34-m elevation under windless conditions. The applicator bucket was 25 m aboveground. The metering gate of the bucket was set at scale 1.15. These application parameters were recommended by Pfizer C & G Inc.[10] and Alpine Helicopters[13] for a 27-m wide target swath in an operational aerial application of this granular formulation.

---

[11]Isolair Series 2600-45 Applicator-Spreader: Isolair Inc., 20490 E. Aschoff Rd., Rhododendron, OR 97049.

[12]Canlab absorbent paper, Cat. No. P1146-10: Canlab, 11620-181 St., Edmonton,Alberta T5S 1M6.

[13] Gubbels, D. 1986. Personal communication. Alpine Helicopters Ltd., 165 George Craig Blvd. N.E., Calgary, Alberta T2E 7H3.

Granules collected in individual trays were weighed to determine deposition rates at different distances from the center of each collection transect. The mean deposition rates and standard errors for each distance and treatment were calculated. The optimal number of sampling trays was estimated with the equation:

$$n = (t^2S^2)/E^2$$

where n = the number of samples; t = Student's t-value; S = standard error; E =expected range of the mean with a defined probability (Freese 1962). The optimal number of samples were calculated for both 20 and 40 kg/ha rates of application with 5-25% accuracies at 5% intervals and with 80, 90, 95, and 99% of certainties, respectively.

5.1.3 Results and Discussion

5.1.3.1 Granule size variation tests

Granule size in the 10-kg lot of blank formulation varied greatly (Fig. 5-1). The average weight of individual granules was 20 mg (n = 315) with a standard deviation of 11 mg (55% CV). Weights ranged from 2.5 to 93 mg. The median was 18 mg, and max.:min. ratio was 37; however, 90% of the granules weighed between 5 and 35 mg. The large variation in granule size may affect the uniformity of active ingredient coverage within a relatively small area.

5.1.3.2 Ground applicator tests

The target rates within the 5-m wide swath were not achieved (Fig. 5-2). Average rates from six replicated transects in the flat area were 11 ± 5 and 16 ± 8 kg/ha for target rates of 20 and 40 kg/ha, respectively (Fig. 5-2, A, B). Granules were distributed unevenly within the 5-m swath (2.5-7.5 m) with two to three-fold differences in the amount of deposition between 2.5-5 m and 5-7.5 m. Less than 5 kg/ha of the granules were found beyond the designated application swath at 10 m. Less than 0.5 kg/ha of granule deposition at 12 m (Fig. 5-2, A, B) indicated that an effective cutoff line could be reached within a reasonably short (5 m) distance beyond the swath edge. Less than 2 kg/ha of the granules escaped from the truck onto the center of the track at 0 m. The artificial bump on the left-hand side track increased the uneven distribution of granules within the designated swath (Fig. 5-2, C, D). Granule size spectrum among trays at various collection distances did not differ noticeably (Table 5-1). Mean percent frequency of granules in different weight classes (Table 5-1) obtained from the ground application was similar to that found in the formulation (Fig. 5-1) but was slightly higher in the lighter weight groups (Table 5-1). Granule size probably is not correlated with distance from this applicator, and the variation in granule size is not expected to impact on the stratified distribution of hexazinone.

Results of the present study indicated that the tested ground applicator has limited use on narrow-strip (5 m) application in forestry practice because of 1) failure to achieve the target rate and uniformity in granule distribution over a narrow swath (5 m) and 2) an inadequate self-adjusting mechanism for compensation for uneven ground on a fine scale.

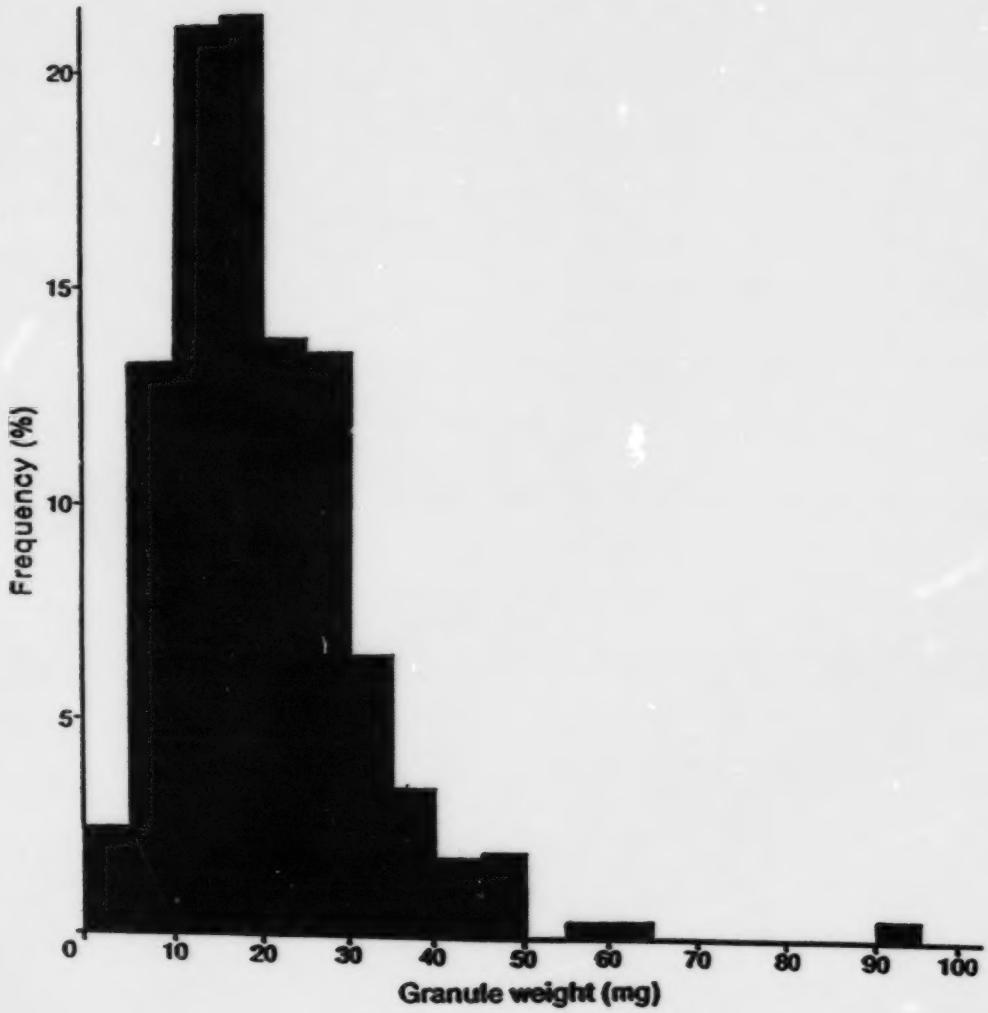

Figure 5-1. Weight distribution of granules with blank protective coating from a 10-kg lot (n = 315).

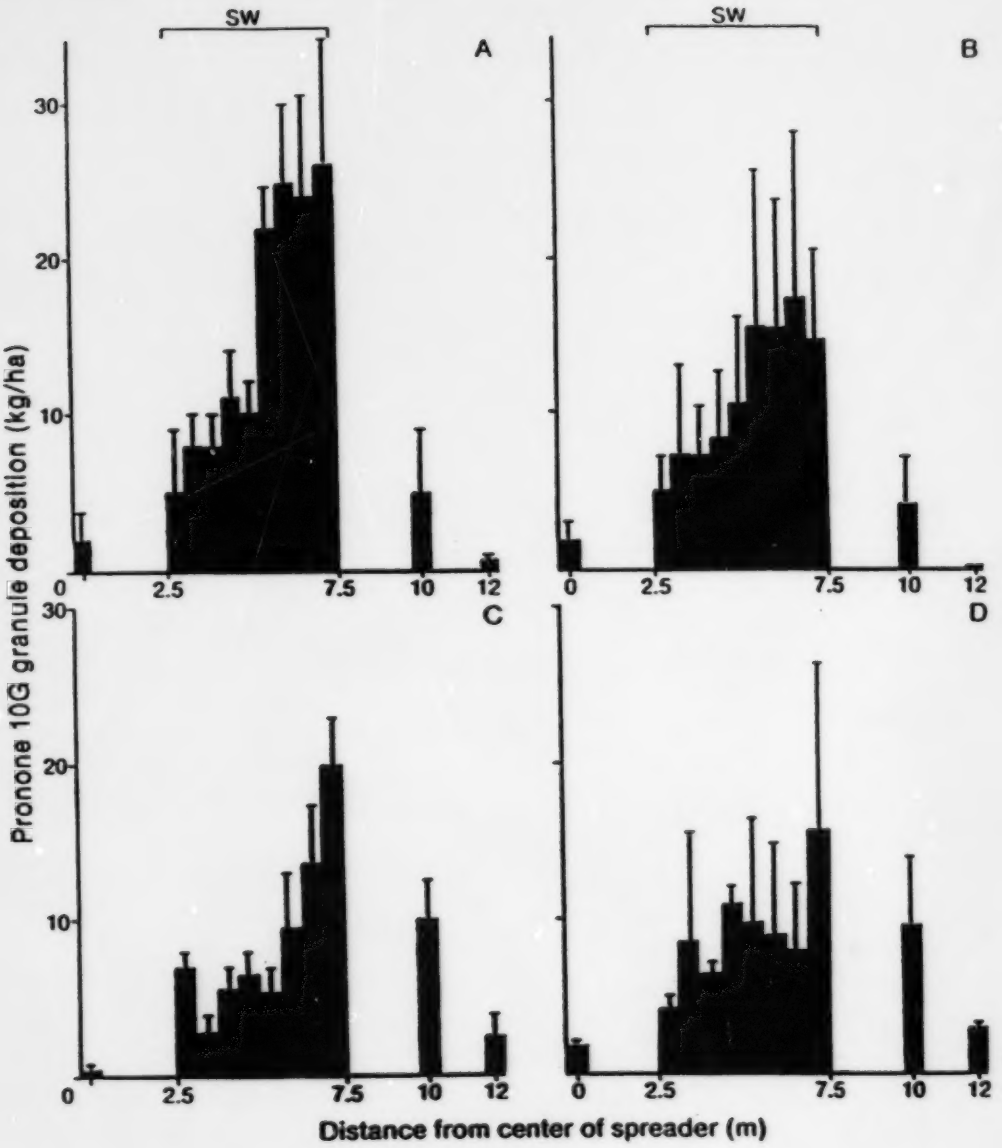

Figure 5-2. Distance deposition rates and distribution profile of granules from the ground application using Ace Rotary Pellet Applicator at 40 kg/ha application on flat ground (A) and with an artificial bump (C), 20 kg/ha on flat ground (B) and with bump (D). SW = designated swath width (5 m).

Table 5-1. Percent frequency of granules of a ground application in weight classes at different delivery distances from the center of a truck-mounted rotary applicator

Rates	Delivery distance	Weight class (mg)								
		5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	>45
(kg/ha)	—(m)—	(%)								
20	2.5-3.1	22	27	27	16	8	0	0	0	0
	3.1-3.6	23	29	15	13	10	5	0	5	0
	3.6-4.2	15	31	22	13	7	8	2	0	2
	4.2-4.7	22	30	26	12	4	2	3	1	0
	4.7-5.3	20	16	22	19	9	4	1	3	1
	5.3-5.8	16	26	20	13	11	5	4	2	3
	5.8-6.4	24	16	22	15	10	4	4	3	2
	6.4-6.9	13	29	26	14	5	3	8	1	1
	6.9-7.5	17	25	21	18	10	4	2	3	0
	Mean	19	25	23	15	8	4	3	2	1
	S.D.	4	6	4	3	2	2	2	2	1
40	2.5-3.1	36	16	18	15	9	4	0	0	2
	3.1-3.6	26	26	29	11	4	1	1	1	1
	3.6-4.2	30	38	14	11	5	0	1	0	1
	4.2-4.7	23	21	17	19	9	7	4	0	0
	4.7-5.3	39	22	15	10	8	5	1	0	0
	5.3-5.8	23	24	26	14	6	2	2	1	2
	5.8-6.4	28	21	18	16	9	4	2	2	0
	6.4-6.9	25	22	20	15	10	3	2	2	1
	6.9-7.5	24	27	21	12	7	4	2	1	2
	Mean	28	24	20	14	7	3	2	1	1
	S.D.	6	6	5	3	2	2	1	1	1

5.1.3.3 Aerial applicator tests

The effective single-swath width during a multiple-swath operational application is defined as the width between two tails of the granule distribution curve at 50% nominal rate. Two single swaths must overlap at the 50% nominal rate point to produce an overall uniform distribution of granules during an operational application. The effective swath width in this study was 27 m for both the 20 kg/ha (Fig. 5-3, A) and the 40 kg/ha (Fig. 5-3, B) applications. The effective swath was centered at the flight path (0 m) with 13 m to the right-hand (R) side and 14 m to the left-hand (L) side. Granule deposition varied from 13% to 75% CV (n = 4) at different distances within the 27-m swath of the 20 kg/ha application; it varied from 4% to 59% CV in the 40 kg/ha application. This large variation indicated that uniform deposition of granules on a small area (0.11 m^2) cannot be achieved with any consistency. A more homogeneous granule deposition was found within the central 22 m of the swath between 11 m (R) and 11 m (L) (Table 5-2). Average rates of deposition were 21 and 42 kg/ha for the 20- and 40-kg/ha applications, respectively, with 20% CV. The granule distribution profiles were different in the two 11-m halves of swath, 0 to 11 m (R) and 0 to 11 m (L), at both rates of application. The average granule deposition on the left half was 18 ± 4 kg/ha and was 76% of that on the right side (23 ± 2 kg/ha) for the 20-kg/ha application; it was 37 ± 6 kg/ha and 77% of that on the right side (47 ± 5 kg/ha) for the 40-kg/ha application.

The 23% to 24% differences between the right and left sides possibly resulted from the design of the metering gate of the Isolair applicator-spreader. The cone-shaped valve of the metering gate for controlling the flow rate of granules was not centered perfectly. It must be perfectly straight to distribute granules evenly to both sides. If the cone-shaped valve is slanted less than 0.5 cm to the left, an estimated 25% fewer granules will be distributed to the left side of the flight line. The alignment of the cone-shaped valve and the metering gate are set in the factory and cannot be adjusted by the operator in the field. However, the differences between the right and left sides may be compensated for by making a double pass at one half of the nominal application rate in opposite directions in small treatment plots or in a crisscross pattern in large operational plots. Average deposit rates within the effective swath width from four transects were 19 ± 5 and 39 ± 9 kg/ha, respectively, for the 20- and 40-kg/ha applications (Table 5-2). On a large-scale operational application, the helicopter-Isolair system could spread granules at the rate specified.

5.1.3.4 Estimates for optimal sampling

Standard errors were increased to 8 kg/ha (42% CV) and 12 kg/ha (31% CV) for the 20- and 40-kg/ha applications, respectively, when using individual values of all trays (n = 112) within the 27-m effective swath. To represent a worst case scenario, the standard error from 112 trays was used to estimate the optimal sample size (Table 5-3).

Fewer trays were required for the double-pass application (40 kg/ha rate) than for the single-pass application (20 kg/ha rate) to achieve the same expected accuracy and probability in estimating the granule deposition of this formulation (Table 5-3). There was a 90% certainty of measuring an average rate of deposition between 36 and 44 kg/ha (40 kg/ha ± 10%) when 27 trays were used to assess the 40 kg/ha rate of application and between 18 and 22 kg/ha (20 kg/ha ± 10%) when 50 trays were used to assess the 20 kg/ha application. Similarly, 38 and 70 trays would be required to achieve the ± 10% accuracy with 95% certainty for assessing the 40- and 20-kg/ha rates of application, respectively. Feng (1988) reported earlier that aerial application by the helicopter-Isolair system showed no change in the pattern of granule deposition under 8 km/h crosswind within a 32-m wide swath. The helicopter-Isolair delivery system probably is the preferred system for applying the new

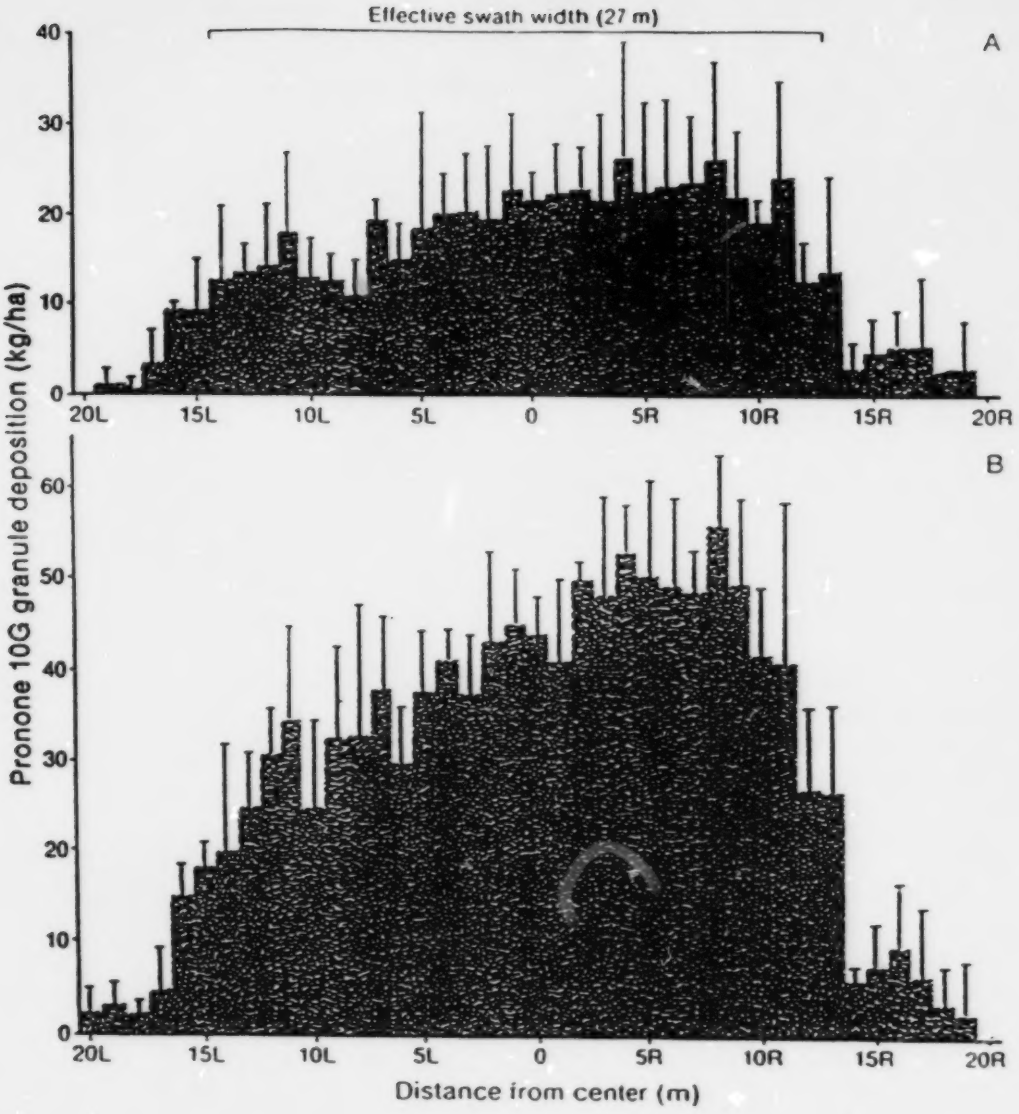

Figure 5-3. Distance deposition rates and distribution profile of granules from the aerial applicaiton using helicopter-Isolair Applicator-Spreader at 20 kg/ha (A) and 40 kg/ha (B) application. R = right-hand side of the swath, L = left-hand side of the swath.

Table 5-2. Mean of averaged (four trays) granule deposition at 1-m spacing within different portion of the distribution profile for aerial application of granules

	Measured deposition rate					
	20 kg/ha application			40 kg/ha application		
Swath width[a]	N	Mean ± S.D.	CV	N	Mean ± S.D.	CV
——(m)——	(no.)	-(kg/ha)-	(%)	(no.)	-(kg/ha)-	(%)
13(R) to 14(L)	28	19 ± 5	25	28	39 ± 9	24
11(R) to 11(L)	23	21 ± 5	22	23	42 ± 8	18
0 to 11(R)	12	23 ± 2	9	12	47 ± 5	10
0 to 11(L)	12	18 ± 4	22	12	37 ± 6	16

[a] (R) and (L): Distance (m) from the flight line (0 m) to the right-hand side (R) and left-hand side (L) of the swath.

granular formulation of hexazinone; and whenever applicable, the nominal rate should be divided into two halves, and a double-pass application in opposite directions or crisscross patterns should be made for a more uniform deposition of granules. The distribution of granules can be improved further by using a potential new formulation containing only 5% active ingredient and by making two and four application passes per swath for a 20- and 40-kg/ha rate, respectively.

5.2 CROSSWIND EFFECT ON ISOLAIR AERIAL GRANULE APPLICATOR[14]

The crosswind effect on the aerial application of granular hexazinone was studied in Grande Prairie, Alberta. A blank formulation of Pronone 10G was used. The granules of the blank formulation were without hexazinone but were surface-coated with the protective layer similar to that of the commercial formulation. The weight of granules of the blank formulation was 10% less than the commercial formulation (less 10% ai). Granules were aerially applied at a nominal 20 kg/ha rate by using a Bell-206 helicopter equipped with an Isolair 2600-45 bucket applicator-spreader under either calm or 8 km/h crosswind conditions. The helicopter flew at 72.4 km/h in one direction at a 33.5 m elevation over a 100-m flight path on levelled ground (6 ha). Two 40-m long sampling transects, perpendicular to and centered on the flight path, were placed at 25 and 75 m. Ten 4-m sections on each transect were marked from the center to both the left-hand and the right-hand sides. Four 0.11 m^2 collection trays were placed in each 4-m section at 1-m spacing. Total weight of granules per 4-m transect was divided by the collection area (0.44 m^2) and then converted to kg/ha deposition rate. Granule distributions under no-wind and 8 km/h crosswind conditions were compared by using the averaged rates of 4 transects from duplicated applications. Results showed that there was no change in the pattern of granule deposition under 8 km/h crosswind, except a slight

[14]Feng (1988).

Table 5-3. Estimated optimal sample size (no. of collection trays) for aerial granule deposition in a 27-m swath width within expected ranges of variation and their probabilities (P) at 20- and 40-kg/ha application rates

Expected rate and range	Estimated optimal sample size			
P =	0.20	0.10	0.05	0.01
(kg/ha ± % rate)	(no. of trays)			
20 ± 5%	117	190	280	480
± 10%	30	50	70	120
± 15%	14	23	32	56
± 20%	9	14	19	33
± 25%	6	10	13	22
40 ± 5%	63	103	145	255
± 10%	17	27	38	66
± 15%	8	13	19	32
± 20%	5	8	12	19
± 25%	4	6	8	14

shift at the tail ends of a transect, i.e., at the 17-20 m section, deposition rate reduced from 2.3 to 0.4 kg/ha at the left-hand side and increased from 1.1 to 3.3 kg/ha at the right-hand side of the swath, when the 8 km/h wind blew from left to right (Table 5-4).

5.3 PERFORMANCE OF ISOLAIR BUCKET SPREADER IN FIELD AERIAL APPLICATION OF PRONONE 10G[15]

Operational application of granular hexazinone with an aerial bucket spreader was evaluated under a 3-year-old clear-cut forest in Grande Prairie, Alberta. The site was dominated by aspen at a 1-m average height. Granular formulation of hexazinone (PRONONE 10G) was aerially applied in three parallel "effective swaths" (defined as two swaths overlapping at tail ends of 50% nominal rate of application to produce a smooth distribution of herbicide) by using an Isolair Series 2600-45 bucket spreader attached to a Bell-206 helicopter flown at 72 km/h at a 34-m elevation under

[15]Feng (1989).

windless conditions. The width of effective swath was determined to be 27 m wide through previous calibration runs. Three parallel effective swaths would cover the width of each treatment plot (80 m wide × 200 m long). Granular hexazinone was applied at two rates, 20 and 40 kg/ha, and each rate was repeated three times. Granule depositions within the central 40 m width were collected at two transects laid at both ends of each plot. Eighty-one polyethylene collection trays (40.5 cm long × 27 cm wide × 10 cm deep) comprising a total surface of 9 m^2 were placed along each transect and were centered lengthwise at each 0.5-m spacing. The distance between trays on the transect was < 0.1 m. Granules from each tray were weighed separately and converted into kg/ha rates. Mean rate of deposition (± SD) varied for every 5-m spacing per plot (n = 20 trays), probably due to swath overlapping at both ends, and is summarized in Table 5-5.

Table 5-4. Crosswind effect on the distribution of Pronone 10G granules applied by using helicopter-Isolair applicator

Distance[a] (m)	N	Deposition of granular hexazinone (kg/ha)			
		Left-hand side		Right-hand side	
		Wind[b]	Calm	Wind[b]	Calm
1 - 4	4	22.4 ± 1.5	24.4 ± 5.0	20.3 ± 3.0	21.2 ± 2.2
5 - 8	4	27.7 ± 5.4	24.1 ± 7.9	16.1 ± 3.8	15.5 ± 4.8
9 - 12	4	19.8 ± 5.8	19.4 ± 4.2	15.4 ± 3.2	14.4 ± 4.7
13 - 16	4	5.8 ± 2.3	6.8 ± 3.9	10.0 ± 2.6	11.0 ± 3.8
17 - 20	4	0.4 ± 0.5	2.3 ± 3.4	3.3 ± 2.3	1.1 ± 1.8

[a] Distance (m) from the center of the application swath (flight path).

[b] Crosswind (8 km/h) blew from the left to right of a collection transect and perpendicular to the flight path.

5.4 PERFORMANCE OF GRANUL-AIR APPLICATOR IN FIELD GROUND APPLICATION OF PRONONE 10G[16]

Distribution of PRONONE 10G granules from a commercially available ground applicator, Granul-Air, was studied in a conifer release research trial in the spring of 1989 in Grande Prairie, Alberta. The site was clear-cut in 1983, and disc-trenched and planted with white spruce and lodgepole pine in 1987. Weed competition was mainly from grasses and aspen at 3 m average height. Two plots each of 80 by 200 m were designated for PRONONE 10G treatment at 20 and 40 kg/ha. Five 30-m transects for granule collection were laid in the center and were evenly spaced along the

[16]Feng, Sidhu, and Feng (1989b).

length of each plot. Fifteen 0.11 m^2 (40.5 cm long by 27 cm wide by 10 cm deep) collection trays were set at a 2-m spacing along each 30-m transect. Granules collected in each tray were weighed and divided by collecting area to give deposition rate (kg/ha). Mean rate of 15 trays per transect were averaged to give mean deposition of each plot. PRONONE 10G was applied by using a truck-mounted Granul-Air applicator under no-wind condition on 30 May 1989. Truck traveled along the length of plot and perpendicular to the collection transects. Means and individual deposition rate of PRONONE 10G granules for each transect are presented in Table 5-6.

Table 5-5. Distribution of Pronone 10G granules within the central 40 m of the 80-m wide plots applied with three overlapping swaths by helicopter-Isolair applicator

Collection distance (m)	Mean rate of granule hexazinone deposition (kg/ha ± SD)			
	Plot 1	Plot 2	Plot 3	Mean ± SD
Treatment 1:	High rate (40 kg/ha)			
0 - 5	34.9 ± 12.9	47.8 ± 16.3	44.4 ± 13.6	42.4 ± 6.7
5 - 10	46.1 ± 11.7	57.8 ± 12.4	55.9 ± 12.0	53.3 ± 6.3
10 - 15	35.6 ± 12.0	42.4 ± 14.3	45.3 ± 14.7	41.1 ± 5.0
15 - 20	29.7 ± 11.0	33.9 ± 12.2	29.8 ± 13.7	31.1 ± 2.4
20 - 25	29.4 ± 14.9	37.4 ± 13.0	28.3 ± 8.5	31.7 ± 5.0
25 - 30	37.0 ± 13.6	42.6 ± 14.4	33.4 ± 10.4	37.7 ± 4.6
30 - 35	34.4 ± 19.5	57.3 ± 14.3	51.7 ± 16.9	47.8 ± 11.9
35 - 40	28.3 ± 11.3	50.8 ± 18.0	44.0 ± 14.8	41.0 ± 11.5
				40.8 ± 7.5
Treatment 2:	Low rate (20 kg/ha)			
0 - 5	23.0 ± 19.8	27.4 ± 10.6	19.0 ± 7.1	23.1 ± 4.2
5 - 10	27.2 ± 17.2	29.1 ± 11.5	16.8 ± 7.1	24.4 ± 6.6
10 - 15	24.2 ± 10.3	19.7 ± 11.8	15.5 ± 7.9	19.8 ± 4.4
15 - 20	18.7 ± 9.5	15.6 ± 5.4	14.7 ± 6.9	16.3 ± 2.1
20 - 25	20.9 ± 9.2	17.3 ± 7.4	17.6 ± 9.3	18.6 ± 2.0
25 - 30	21.7 ± 11.5	19.7 ± 7.0	25.8 ± 11.3	22.4 ± 3.1
30 - 35	34.7 ± 19.9	24.1 ± 11.3	38.1 ± 14.8	32.3 ± 7.3
35 - 40	34.8 ± 18.4	18.4 ± 8.6	36.9 ± 11.8	30.0 ± 10.1
				23.4 ± 5.5

Table 5-6. Distribution of Pronone 10G granules at each transect and their means for four separate plots treated at two different rates by using a tractor-mounted ground applicator, Granul-Air

Transect	Low dosage treatment		High dosage treatment	
	(kg/ha ± SD)			
1	23.4	14.6	55.6	59.6
2	18.3	27.3	73.7	53.6
3	20.2	22.8	48.1	63.5
4	25.3	22.4	51.0	62.2
5	15.4	27.3	50.9	58.3
Mean	20.5 ± 4.0	22.9 ± 5.2	55.9 ± 10.3	59.5 ± 3.9

The overall mean deposition rates of the low and high dosage treatments were 21.7 and 57.7 kg/ha, respectively. The low dosage application was calibrated before field treatment, which showed within 10% of the target rate. However, the high dosage application was not calibrated but proportionally set on the computer dial according to the low dosage calibration, and was over 40% higher than the target rate of 40 kg/ha. It was also observed that the truck tended to throw more granules to its right-hand side. This problem might be associated with the hydraulic design and wear-and-tear of the Granul-Air applicator.

5.5 DETERMINATION OF HEXAZINONE DEPOSITION FROM A LOGARITHMIC SPRAYER[17]

5.5.1 Background

Hexazinone is a residual, systemic herbicide taken up by plants primarily through the root system (Ghassemi et al. 1981). It is used as a selective herbicide for conifer release and preplanting site preparation (Malik and Vanden Born 1986). The application rates for hexazinone depend on a variety of factors such as the type of weeds (grasses, forbs, and brush) to be controlled, and more importantly, the texture and organic matter content of the soil. Although a range of application rates for a variety of site descriptions has been investigated in the United States (Boyd et al. 1985; Cantrel 1985; William et al. 1987), little information is available on the appropriate application of hexazinone under boreal site conditions. To investigate the biologically and economically effective rates required for a particular set of site conditions, the use of a logarithmic sprayer can be an important and simple tool. The logarithmic sprayer applies herbicide at various rates in one application, allowing the researcher to determine which rate provides the best efficacy and crop tolerance on a specific site. The use of a logarithmic sprayer thus may reduce the need for the large number of subplots usually required in testing a broad range of single application rates. It may also reduce the need for large quantities of herbicides in research trials, thereby reducing the unnecessary risk of environmental contamination.

[17]Feng, Ehrentraut, and Drew (1989).

The Model 725 Steady-Dilution-Logarithmic-Sprayer[18] operates by continuously diluting herbicide over time and distance on a logarithmic scale so that a linear swath may be sprayed with a predetermined range of application rates. The expected change in rates within each plot can be calculated according to the manufacturer's specifications for this instrument; however, the mathematically and laboratory-generated model and the actual performance of a logarithmic sprayer should be verified through field trials (Neary et al. 1983). The objective of this study was to determine the performance of a logarithmic sprayer by measuring the deposition rates of hexazinone based on a nominal decreasing log scale (from 9 to 0.56 kg/ha) in small plot (2 × 50 m) trials under boreal forest conditions.

5.5.2 Materials and Methods

5.5.2.1 Site description

The experimental site was located in the Wandering River Ranger District of the Lac La Biche Forest in Alberta. The plots were 42 km north of the town of Wandering River. Before a forest fire swept through the area in 1981, the parent stand was 100-120-year-old mature spruce-aspen. The area was salvage-logged in the winter of 1982, then cleared and windowed, and the piles were burned in 1983. Bracke scarification was carried out in 1984, and container-grown seedlings of white spruce were planted in the spring of 1985.

Soils in the area are loam to silt loam (44% sand, 40% silt, 16% clay) and are easily erodible. The site saturates quickly, suggesting a shallow water table. Vegetation on the site includes a cover of 43% reed grass (*Calamagrostis canadensis*) and 15% low shrubs. Hardwood density is patchy, with an average of 27 500 stems/ha, which are mostly alder with an average height of 1 m.

5.5.2.2 Experimental plots

Four plots were laid out for a single swath application. Each plot was 2 m wide and 60 m long. The spray equipment and application were calibrated to run for 90 seconds and to cover the first 50 m. The additional 10 m on each plot was a control area for vegetation assessment and was not sprayed. Each 2-m wide plot was transected 10 times, at 5-m intervals, starting at 5 m from the high-rate (9 kg/ha) end. At each transect, two posts were placed on the center of each side: one post 0.5 m to the left and another post 0.5 m to the right of center. Deposit collectors were placed on top of each post flush with the top of the vegetation canopy at 1.5 m aboveground.

5.5.2.3 Herbicide application and logarithmic sprayer

Velpar L, a liquid formulation of hexazinone, was applied using a backpack sprayer fitted with a four-nozzle boom and a Model 725 Steady-Dilution-Logarithmic-Sprayer. The sprayer was calibrated for a 2-m wide effective swath. The operator traveled the 50-m length of the plot in 90 seconds, down the center line of the swath, with the spray boom 1 m above deposit collectors (2.5 m aboveground). The actual time and distance of each application were measured and recorded.

The logarithmic sprayer is designed to dilute a known quantity of chemical on a logarithmic scale over time and distance during spraying. It contains two bottles: Bottle A (0.5 L) and Bottle B (2.0

---

[18]R & D Sprayers, Inc., Opelousas, LA.

L). Bottle A contained the Velpar and water mixture, which was calculated to produce an initial application rate of 9 kg/ha. Bottle B contained only distilled water for diluting the contents of Bottle A. The water in Bottle B was pressurized and flowed into Bottle A when the spray valve was open, thus increasingly diluting the herbicide at a log rate of application. When Bottle B (2.0 L) was empty, the spray stopped. Based on the specification of the log-sprayer, the total volume of water in Bottle B would provide four one-half dilutions to the initial herbicide concentration in Bottle A. Therefore, at the completion of an application, Bottle A still retained a diluted mixture of hexazinone at a calculated concentration equivalent to an application rate of 0.56 kg/ha. Prior to herbicide application, the operator practised the operation several times outside the treatment plots by using only distilled water to completely apply the 2 L volume of water (Bottle B) over a distance of 50 m in 90 seconds.

5.5.2.4 Deposit collection

The petridish collector and method of Feng and Klassen (1986) were used to collect spray deposition. The filter paper liner of the collector was modified from Feng and Klassen by using Whatman No. 934-AH glass microfiber filters instead of Whatman No. 114 filter paper. After spraying, the petri dishes were closed and taped shut and placed in a labeled plastic bag and kept frozen for one month before analysis for hexazinone residues.

5.5.2.5 Residue analysis

By using methanol, hexazinone residues were extracted and diluted from the deposit collectors based on the method of Feng and Klassen (1986). Methods of gas chromatographic analysis (Feng, Feng, and Sidhu 1989), specific analytical conditions (Feng, Sidhu, Feng, and Servant 1989), and hexazinone peak quantitation (Feng 1987) were reported earlier. Deposition samples from the two sets of collectors per transect (one set from each side of the center line of a swath) were analyzed separately. Hexazinone residues were then pooled to give the total residues per transect.

5.5.2.6 Statistical analysis

The total amount of hexazinone (mg) per transect per plot was divided by the respective total collection area (cm^2) and was converted into kg/ha. Hexazinone deposition rates of individual treatment plots and their means in relation to distances were analyzed by using the following regression model:

$$\text{Log } Y = A_o + A_1 X$$

where Y is the rate of deposition (kg/ha) and X is the distance (m) from the starting line of herbicide spraying.

The expected regression model was calculated with the same equation based on four one-half dilutions over a total distance of 50 m, as specified by the manufacturer

Distance (m):	0	12.5	25.0	37.5	50.0
Nominal rates (kg/ha):	9	4.5	2.3	1.1	0.56

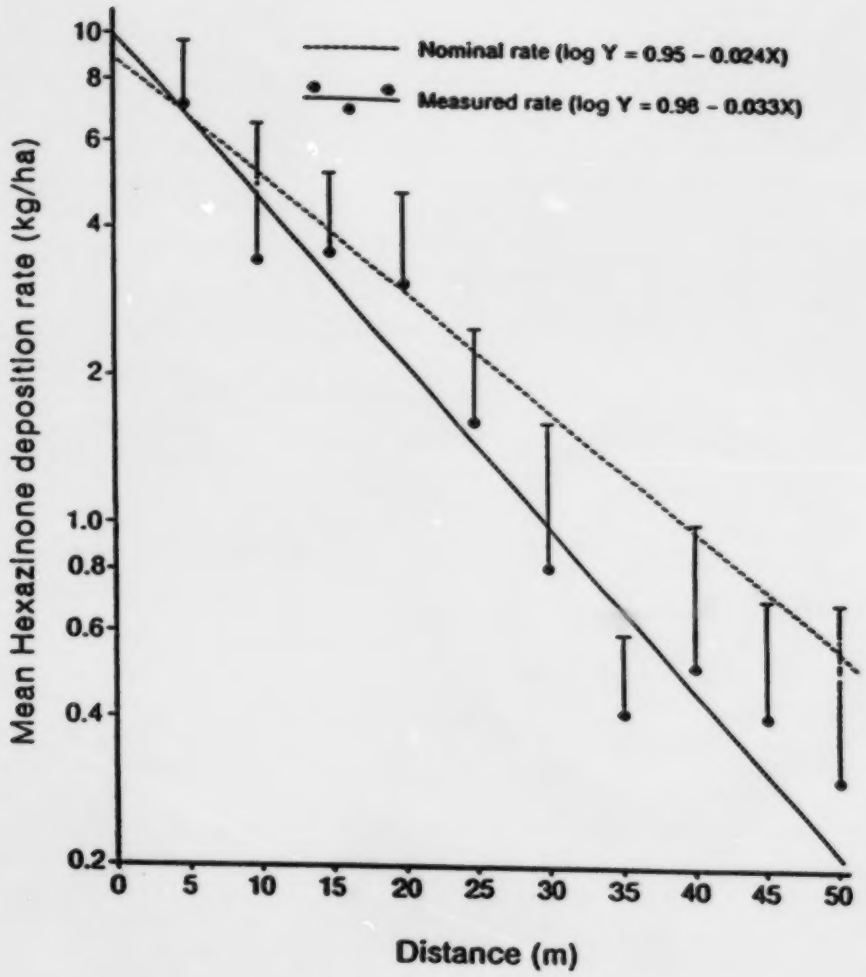

Figure 5-4. Mean hexazinone deposition of four plots collected between 5 and 50 m in each plot after application with a backpack logarithmic sprayer.

and was: Log Y = 0.95 - 0.024 X. The expected (nominal) deposition rates were calculated from this model for 10 equivalent transects between 5 and 50 m in each treatment plot.

5.5.3 Results and Discussion

Average deposition rates of hexazinone of four plots at 10 transects are shown in Figure 5-4. Although the average time and distance of application for each plot (n = 4) was consistent at 50 ± 0.7 m (1.3% CV) in 90 ± 1.0 sec (1.1% CV), there were differences in deposition rates among plots at identical collection distances. At the 5-m transect, the average deposition rate was 7.2 ± 2.3 kg/ha, which was slightly higher than the expected rate of 6.8 kg/ha. Greater variation was observed at the 10-m transect (3.4 ± 3.3 kg/ha), and the value was much lower than the expected rate of 5.2 kg/ha. Average deposition rates at the 15- and 20-m transects were 3.6 ± 1.6 and 3.1 ± 1.7 kg/ha; these were the closest to the expected rates (3.9 and 3.0 kg/ha). The average deposition rate at the 30-m transect was 0.8 ± 0.8 kg/ha, one-half of the expected rate of 1.7 kg/ha. The minimum expected rate (0.56 kg/ha) was reached at the 35-m transect instead of at the expected distance of 50 m. The deposition of hexazinone seemed to be similar between 35 and 50 m and was near the minimum expected level. Although the total time and distance of application were well controlled, the way of walking of the operator as well as interference from ground vegetation may have caused some variations in hexazinone deposition among collection transects at the same distance. Another cause of variation may be due to the compatibility between the nozzle type and deposit collectors. Droplet spectra vary according to the nozzle types (Payne et al. 1987). In this case, larger deposit collectors, i.e., sheet collectors (Feng and Klassen 1986; Payne et al. 1987), might be more suitable in controlling the size variation of droplets, in turn producing a more uniform collection of deposits. However, the faster rate of reduction in hexazinone deposition observed in all plots reflected a faster dilution rate of hexazinone in the logarithmic sprayer during application than the expected rate based on the mathematical and laboratory model.

Regression models of the log-transformed rate of deposition (kg/ha) on distance (m) are given in Table 5-7. Tests were made on individual plots, as well as on the means of two, three, and four plots. The correlation coefficients (R) were improved when the number of replications was increased and mean values were used. Individual plots showed a range of R between 0.81 and 0.85. When any of the two plots were averaged, R values increased to 0.88-0.96, and they increased to 0.96-0.97 when three plots were averaged. There was no further improvement in R when all four plots were averaged (R = 0.97). Results suggested that to use the logarithmic sprayer effectively in silvicultural trials, the actual deposition of hexazinone should be analyzed and repeated no fewer than three times. A similar trend of improvement was observed by comparing the intercepts (A_0) of the regression models. The range of intercepts was 0.80-1.14 when individual plots were analyzed. The ranges narrowed to 0.87-1.10, 0.98-1.06, and 0.98 when means of two, three, and four plots were employed, respectively, and were increasingly closer to the expected value of 0.95. In all regression models, the slopes (A_1), ranging from -0.026 to −0.051, were significantly greater than the expected slope of -0.024. Results suggest a faster rate of reduction in hexazinone deposition over a given distance than the mathematically and laboratory-generated value. The operator should exercise caution when using a logarithmic sprayer. The pattern of rate reduction may vary depending on the construction of the individual sprayer, type of boom and nozzles, ground or vegetation obstructions, and the way that the operator paces. Prior to field efficacy trials, the actual pattern of deposition of active ingredient should be established to provide a reasonable assessment of vegetation responses and for studying the cost-effective application of hexazinone.

5.5.4 Summary

Effectiveness of the herbicide hexazinone in controlling competing grass and brush in Alberta's regenerated conifer forest is believed to be highly dependent on site factors such as soil texture and the presence of organic matter. Currently there is little factual understanding of these relationships. In order to provide a basis for operational decisions and for more discriminate analysis, the logarithmic sprayer approach was adopted as an appropriately low-cost, first-cut solution. The work reported here evaluates the performance of the logarithmic sprayer in providing definable concentrations over the relative distance of the application path. The sprayer was shown to be sufficiently accurate for this work, when three or more replications were averaged, with 95 % of the variation in concentration deposited explainable on the basis of distance travelled. This report is a prelude to subsequent work, which will address the question of hexazinone concentration rates and their efficacy in controlling target species on a range of soil textures and organic contents.

Table 5-7. Equations Illustrating Deposition of Hexazinone by Distance within a 2 X 50 m Plot Treated with a Backpack Logarithmic Sprayer

Treatment	Equation	R	N
Plot 1	Log Y = 1.10 - 0.046 X	0.85	10
Plot 2	Log Y = 1.14 - 0.037 X	0.81	10
Plot 3	Log Y = 1.13 - 0.051 X	0.83	10
Plot 4	Log Y = 0.80 - 0.026 X	0.83	10
Plots 1,2	Log Y = 1.07 - 0.036 X	0.93	10
Plots 1,3	Log Y = 1.09 - 0.045 X	0.88	10
Plots 1,4	Log Y = 0.87 - 0.031 X	0.89	10
Plots 2,3	Log Y = 1.10 - 0.038 X	0.90	10
Plots 2,4	Log Y = 0.99 - 0.029 X	0.96	10
Plots 3,4	Log Y = 0.88 - 0.032 X	0.89	10
Plots 1,2,3	Log Y = 1.06 - 0.036 X	0.96	10
Plots 1,2,4	Log Y = 0.98 - 0.031 X	0.97	10
Plots 2,3,4	Log Y = 0.99 - 0.032 X	0.97	10
Plots 1,2,3,4	Log Y = 0.98 - 0.033 X	0.97	10
Expected	Log Y = 0.95 - 0.024 X	1.00	10

Note: Y is rate of hexazinone deposition (kg/ha); X is distance (m) from the starting line of spraying. Expected rate was calculated based on the specifications of the log-sprayer.

5.6 SAMPLING FOR ZERO-TIME HEXAZINONE RESIDUES IN FOREST SOILS FOR DISSIPATION STUDY[19]

5.6.1 Background

In forestry, liquid formulations of herbicides are commonly applied by broadcast spraying, either aerially or on-ground. Reliable monitoring of herbicide deposition and residue levels is a prerequisite for efficacy and environmental studies. Residue levels detected in soil samples taken immediately (zero-time) or shortly after application are often found to be lower than both the rate of application and the residue levels in soil samples taken several days later. This problem may be caused by deficient methods of soil sampling.

Traditionally, forestry soil sampling methods of residue monitoring have been adapted from those used for agricultural soils where herbicide residues were usually reported on a concentration basis (μg/kg; ppb) (Feng and Klassen 1986; Thompson et al. 1984). To account for variable bulk densities of forest soils and to allow the conversion of soil residue concentrations (μg/g; ppm) to the application rate equivalent (kg/ha), the sampling and reporting methods for herbicide residues in forest soils were recently improved by measuring total sample weight, sampling depth, and surface area with the aid of a Campbell soil auger (Feng and Campbell 1985; Feng and Klassen 1986). These methods were applied later in studying the persistence of herbicides in Canadian forest soils for both glyphosate (Feng and Thompson 1989; Roy, Konar, Banerjee et al. 1989) and hexazinone (Feng and Campbell 1985; Feng and Feng 1988a,b; Feng, Feng, and Sidhu 1989; Roy, Konar, Charles et al. 1989; Prasad and Feng 1990).

Thompson et al. (1984) studied the persistence of 2,4-D and 2,4-DP in four Ontario soils using a box corer and reported that the zero-time soil residue concentrations (μg/kg) were 60-70% of the expected level, and increased up to 10-300% in most soil samples 1-7 days after spraying. Although no direct comparison could be made, they speculated that 30-40% of the chemical might be lost due to interception by vegetation, drift, and volatilization at the time of application, and then carried back into soils by dripping or washing off the foliage by dew. Feng and Feng (1988b) proved that hexazinone levels in zero-time soil samples (1.99 kg/ha) were 27% lower than that actually deposited on the forest floor (2.53 kg/ha) and increased slightly (10%) when 29 mm of rainfall occurred 5 days after spraying.

It is evident that rainfall would carry the water soluble residues of hexazinone from the surface of the forest floor into deeper soil layers (Feng, Sidhu, Feng, and Servant 1989). However, the cause of increases of herbicide residues from the zero-time soil samples to those several days after application remained unclear. This was further documented by Roy, Konar, Banerjee et al. (1989) and Roy, Konar, Charles et al. (1989) in two herbicide studies in both the presence and the absence of rain events. On a clay site applied with 3.5 kg/ha hexazinone, they reported that zero-time soil residues (0.9 kg/ha) increased steadily to 1.5 kg/ha and 2 kg/ha after 7 and 14 days, respectively, when rainfall started and accumulated to 55 and 75 mm (Roy, Konar, Charles et al. 1989). However, glyphosate (applied at 1.8 kg/ha) increased from 0.9 kg/ha in sandy soils at zero-time to 1.7 kg/ha, 1 day after spraying, even though there was no rain (Roy, Konar, Banerjee et al. 1989).

Feng and Feng (1988b) suggested that these observed anomalies in herbicide residues were caused by losses in the zero-time soil samples due to the direct contact of sampling instrument and sample storage container with the thin layer of herbicides deposited on the surface of soils. To avoid

---

[19]Feng and Navratil (1989, 1990).

contact losses of residues at zero-time, they recommended a new soil sampling method using glass jars (Feng and Feng 1988b). The new glass jar method was tested under forest conditions in the Calling Lake Ranger District (Satellite trial A), northern Alberta. The effectiveness of the glass jar method in comparison with the conventional corer method and the zero-time residues and dissipation of hexazinone (Velpar L) in forest soils over a one-year monitoring period are documented.

5.6.2 Materials and Methods

5.6.2.1 Experimental site and herbicide application

The study site was located in the Calling Lake Ranger District (55°5′ N, 113° 30′ W), 200 km north of Edmonton, Alberta. The site was logged and windowed in the winter of 1985-86. Soils of the area are orthic gray luvisol with textures of silty loam to sandy clay, covered by an organic layer 8 cm thick (Navratil and Lane 1987). Four plots, 42.5 × 50 m, were randomly selected and treated with a liquid formulation of hexazinone (Velpar L) at 3 kg ai/ha nominal rate by means of a backpack sprayer. The treatment was a component of a larger trial (Satellite trial A; Navratil and Lane 1987) designed to compare methods for controlling aspen competition. The herbicide was applied on 18 September 1986 when the relative humidity was 42%, the air temperature 13°C, and wind velocity 13 km/h from the south.

5.6.2.2 Soil sampling

Sampling for residue levels of hexazinone in soils at zero-time, ie, immediately following application, was done by two methods: a glass jar method (Feng and Feng 1988b) and a corer method (Feng and Klassen 1986). The latter was also used for the subsequent postapplication samplings.

Glass jar method. Sixteen glass jars, 10 cm deep and 10 cm in diameter, were filled to 5 cm depth (half full) with uncontaminated surface soil (0-15 cm layer) collected prior to hexazinone application at the experimental site. Glass jars were evenly distributed in four treatment plots and buried in the ground with the mouth of the jars flush with the surface of the forest floor, i.e., at the top of the organic horizon. Immediately following application, the glass jars were filled with uncontaminated prespray soils to cover the thin layer of hexazinone deposited on the surface of soils inside the jars. The jars were then collected, sealed, and placed in a cooler filled with ice for transporting to cold storage (-20°C) where they were kept for about one month before further processing. Pre-weighing of soil to be added to each glass jar before and after spraying was not necessary. This simplified the field procedures.

Corer method. A Campbell soil auger (Feng and Klassen 1986) was used to collect from each plot four 10-cm diameter soil cores to 30 cm depth. The soil cores were divided into two 15-cm sections, i.e., 0-15 cm and 15-30 cm in depth, respectively, measured from the surface of the forest floor. These soil core sections were packaged separately and stored as described above. Three collections of soil samples were made during the one-year monitoring period at 0, 210, and 360 days after application.

5.6.2.3 Residue analysis and reporting

Soil samples collected at the same time by the same method were pooled, air-dried, weighed, and homogenized by the method of Feng and Klassen (1986). Residues of hexazinone were extracted and purified from soils according to the modified method of Holt (1981) in Feng (1987). Gas chromatographic analysis was performed by A&E Environmental Testing[20]. Residue concentrations (μg/g; ppm) of hexazinone were calculated by comparison with the average peak height from the analytical grade hexazinone standard[21] analyzed immediately before and after each sample (Feng, Feng, and Sidhu 1989). Total sample weight, sampling depth, surface area, and individual bulk densities were then used to convert residue concentration to an areal basis (kg/ha) (Feng and Klassen 1986). Since the variation of soil core weight was controlled, all residue samples thus reported could be compared directly on an equal basis.

5.6.3 Results and Discussion

Zero-time residue levels of hexazinone in soils collected immediately after spraying using the glass jar and the corer method were 3.8 and 0.8 kg/ha, respectively (Table 5-8). The glass jar method produced about five times more hexazinone residues than the corer method at zero-time. The major difference in approach of these two methods was that the former provided a protective layer of soil after spraying, on top of the thin layer of hexazinone deposited on the exposed soil surface inside the glass jar; while the latter lost part of this thin layer of chemicals to sampling tools and the inner surface of the sample container by contact and handling (Feng and Feng 1988b). In the present study, soil samples collected at zero-time by the conventional corer method lost 75% of hexazinone residues as compared to the nominal rate of application. The percent loss was similar to that reported by Thompson et al. (1984) on 2,4-D and 2,4-DP, that by Roy, Konar, Banerjee et al. (1989) on glyphosate, and that by Roy, Konar, Charles et al. (1989) on hexazinone. Feng and Feng (1988b) also reported that residues of hexazinone in the zero-time soil samples were 52% of the application rate when the conventional sampling method was used. Results of the present study support the explanation that zero-time residues are vulnerable to contact-loss to sampling tools and handling rather than to losses through other pathways such as drift and volatilization (Feng and Feng 1988b).

The chemicals applied initially may be carried from the surface into deeper soils by adequate moisture, such as rainfall, dew, and snowmelt (Feng, Sidhu, Feng, and Servant 1989). The susceptibility of the applied chemicals to contact-loss would then be greatly reduced, depending on the degree of chemical penetration and dilution by the volume of underlying soils. Thereafter, reliable residue samples may be collected by conventional methods. Overwinter sampling by the corer method indicated that hexazinone residues in the 0-15 and 15-30 cm soil layers were equivalent to 1.5 and 0.5 kg/ha, respectively, 210 days after spraying. The corresponding values were 0.25 and 0.1 kg/ha after 360 days (Table 5-8). The total residues (0-30 cm layer) found in the 210-day samples were 2 kg/ha, 50% that of the glass jar method at zero-time but three times higher than that obtained with the same method (corer method) at zero-time. These observations further illustrated the possible risk of sampling for zero-time soil residues using the conventional corer method and demonstrated the reliability of the new glass jar method.

---

[20]Stupp, S.P. 1987. Personal communication 1987. P.O. Box 130, Temple, PA 19560.

[21]99.9% pure, supplied by E.I. du Pont de Nemours & Co., Walker's Mill, Barley Mill Plaza, Wilmington, DE 19898.

Table 5-8. Hexazinone residue levels detected in soils at zero-time by means of a glass jar method, and at 0, 210, and 360 days after spraying by means of a corer method

Sampling method	Days after spraying	Hexazinone residue level (kg/ha)		
		Upper layer	Lower layer	Total
Glass jar	0	3.8	-	3.8
Corer	0	0.8	0	0.8
Corer	210	1.5	0.5	2.0
Corer	360	0.25	0.1	0.35

Note: Sampling depths for the corer method were: 0-15 cm for upper layer; 15-30 cm for lower layer; and 0-30 cm for total.

The dissipation rate of hexazinone found in this study, when data for the glass jar and the corer methods were used for zero-time and the subsequent samplings, respectively, appeared to be a fortuitous linear function of time (Fig. 5-5). It did not follow the commonly accepted regression model using log-transformed concentrations of residues and postapplication times (Feng and Campbell 1985; Feng and Feng 1988b; Roy, Konar, Banerjee et al. 1989; Roy, Konar, Charles et al. 1989; Thompson et al. 1984). Results of the linear regression analysis indicated that the dissipation time for 50% of hexazinone (DT_{50}) in the 0-30 cm layer of soil was 206 days. This slow DT_{50} was probably caused by the late season application followed by a 6-month winter. In a laboratory study, Bouchard et al. (1985) found that the DT_{50} for hexazinone increased from 2.5 months to 1.2 years, when soil temperature was reduced from 30 to 10°C. It seemed that the hexazinone level (2 kg/ha) detected in April 1987, 210 days after spraying, might have been reached six months earlier in late October 1986, and residues had been preserved in soils after the ground-freeze and over the winter. Similar slow dissipation rate of hexazinone in late fall was also reported in other northern Alberta soils (Feng and Feng 1988a). Rhodes (1980a) suggested that hexazinone is degraded by microbial action in soils. It is most likely that microorganism activity in the soil would stop when the average winter soil temperature at the site was -10°C. If the winter months were deducted from the total exposure time to allow only the active time for hexazinone degradation, the DT_{50} would then be about one month and similar to those reported by other researchers using log-transformed residue levels and time after application (Feng and Campbell 1985; Feng and Feng 1988b; Rhodes 1980a; Rhodes, Krause, and Williams 1980; Roy, Konar, Charles et al. 1989). With the aid of reliable soil sampling methods, studies can be conducted to assess the effect of low temperature as well as the warmer climate on the dissipation rate of hexazinone and other forestry herbicides.

The use of the glass jar method should be extended from the zero-time up to several days after herbicide spraying until the first occurrence of rainfall, by allowing jars continuously exposed under the field conditions. Glass jars should be filled to the top with uncontaminated soils only until the time of the next scheduled sampling so that photodegradation, evaporation, and other degradation pathways can be estimated. Because leaching will move herbicide deeper and affect degradation rate (Feng, Sidhu, Feng, and Servant 1989), and herbicide cannot leach in the glass jar, this sampling method is not suitable for continuing field trials when leaching of herbicide through the soil profile is initiated and maintained by movement of soil water. Therefore, in estimating the dissipation rate of a liquid herbicide in soils, best results would be obtained by the combined use of both sampling

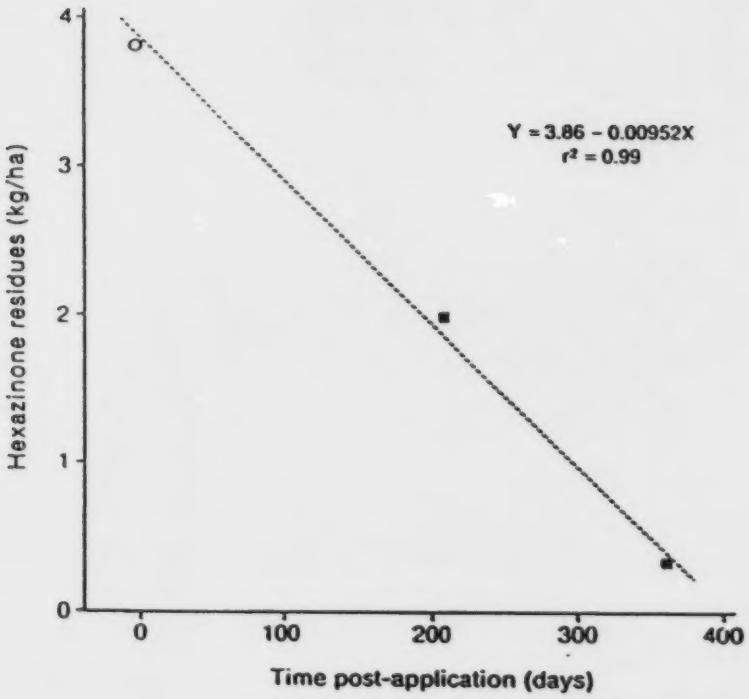

Figure 5-5. Dissipation of hexazinone in northern Alberta soils. Experiments were initiated on 18 September 1986 at Calling Lake Ranger District. Mean residue values of hexazinone (four replicates) were obtained by means of two sampling methods: a glass jar method (o) for the surface soils at zero-time and a corer method (■) for the 0-30 cm soil layer in the subsequent samplings, and presented with linear regression equation (----).

methods: the glass jar method for samplings between zero-time immediately after spraying and before the first rainfall in conjunction with the conventional corer method for subsequent soil samplings.

5.7 NEW ANALYTICAL METHODS FOR DETERMINATION OF HEXAZINONE RESIDUES IN SOIL AND VEGETATION SAMPLES[22]

5.7.1 Background

Residuesofhexazinone,3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione, and two primary metabolites, 3-(4-hydroxycyclohexyl)-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione (metabolite A) and 3-cyclohexyl-6-(methylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione (metabolite B) in soils were determined by initial extraction with methanol, cleanup by a new microcolumn technique, and measurement by direct capillary gas chromatography without derivatization. This new method used less than 30% of organic solvents and was five times more efficient than the modified method of Holt (Feng 1987; Feng and Feng 1988b; Holt 1981). For the cleanup of vegetation samples, the method for soils was modified to remove chlorophyll from plant extracts which could not be removed efficiently by the conventional method of Holt (1981).

5.7.2 Microcolumn Method for Determination of Hexazinone in Soils

5.7.2.1 Sample preparation

Soil core sections were air-dried in separate trays in an insulated dark room with a dehumidifier running at high speed for several days until soil moisture content stabilized at about 3-5% oven-dried weight. The air-dried soil samples were then homogenized, sifted through a 2-mm mesh sieve, and mixed thoroughly (Feng and Klassen 1986).

5.7.2.2 Microcolumn preparation

The bottom end of a 10-mL disposable glass volumetric pipet was plugged with glass wool. A 3-mL bedding of anhydrous Florisil was packed into the glass pipet with light tapping on its side. A second 3-mL bedding of neutral aluminum oxide (Al_2O_3) was added on top with tapping and was followed with a 1-mL layer of anhydrous sodium sulfate (Na_2SO_4) prewashed with chloroform. Dry packing technique was used and no prewashing was required prior to sample loading. The liquid displacement volume was about 5 mL.

5.7.2.3 Sample cleanup

A 20-g aliquot of the processed soil sample was weighed into a 250-mL Nalgene polymethylpentene centrifuge bottle (Nalge 2107), added with exactly 200 mL methanol, capped tightly, and shaken horizontally for 15 min on an Eberbach reciprocating shaker at 280 excursions per minute. The sample was then centrifuged at 350 × *g* for 10 min to separate soil and methanol extracts. About 160 mL of extracts were carefully poured, without disturbing the soil precipitate, through a Millipore assembly consisting of a 47-mm Teflon-faced glass filter holder assembly and a

---

[22]Feng, J.C. (Unpublished results.)

0.45 μm HVLP Durapore membrane filter. Exactly 150 mL of filtrate (equivalent to 15 g soil) were measured with a 250-mL graduated cylinder and quantitatively transferred (with 3 × 5 mL of methanol rinse of the cylinder) into a 500-mL round bottom flask. The neck of the flask was rinsed with small amounts of methanol. The volume of filtrate was reduced to about 3 mL by using a rotary evaporator at 45°C under reduced pressure. The concentrated content was quantitatively transferred (with 3 × 2 mL methanol rinse) into a 15-mL graduated conical tube with Teflon-lined cap. The sample volume was reduced to 5 mL under a stream of nitrogen by using a N-Evap (Organomation Assoc. Inc., South Berlin, MA) and then was loaded on the dry-packed microcolumn with 3 × 0.5 mL methanol rinse. The microcolumn was eluted with 15 mL of methanol (the eluent was the same solvent as for extracting solution). All eluates were collected into a 15-mL graduated conical tube and evaporated to dryness with nitrogen in a N-Evap. Two mL of toluene (or predetermined volume between 1 and 10 mL depending on the predicted residue concentrations) were added to the sample tube to redissolve residues before gas chromatographic analysis (Figs. 5-6).

5.7.2.4 Gas chromatography

A capillary gas chromatograph (GC) was used to determine concentrations of residues of hexazinone and the two primary metabolites A and B. The specific gas chromatographic conditions were as follows:

Gas Chromatograph: Varian Model 3500 Capillary GC equipped with a megabore injector, a Thermionic Specific Detector (a nitrogen-phosphorus detector), a Model 8035 autosampler, a Varian DS 654 data system, and a NEC Pinwriter P6 printer-plotter.

Chromatographic Column: 30-m J&W fused silica DB-17 column, 0.325 mm inside diameter, 0.25 μm film thickness.

Temperatures: Injector, 250°C; detector, 300°C; oven temperature program, 80°C (2 min) - 250°C (30°C/min; held for 12 min) total run-time = 20 min.

Gases: Carrier gas, helium (Ultra Pure grade) 4.3 mL/min at 50°C; linear velocity, 57 cm/s at 50°C; head pressure, 110 kPa; make-up gas, nitrogen (Ultra Pure grade) 30 mL/min; plasma gases, air (Zero Gas grade) 175 mL/min; hydrogen (Ultra Pure grade) 4.5 mL/min. (All gases were supplied by Liquid Carbonic, Edmonton, Alberta.)

Retention Times: Hexazinone, 13.3 min; metabolite B, 14.0 min; metabolite A, 17.4 min.

Residue Peak Quantitation: Use of reference standards (99.9% pure) in peak height quantitation was reported earlier (Feng 1987; Feng and Feng 1988b; Feng, Ehrentraut, and Drew 1989; Feng, Feng, and Sidhu 1989; Feng, Sidhu, Feng, and Servant 1989) and can be summarized as follows: a mix-standard solution containing 2.5, 5.0, and 10.0 μg/g of hexazinone, metabolite B, and metabolite A, respectively, was analyzed immediately prior to and after each sample analysis. When an analyzed sample showed twice or more the concentration of standard solution, the sample was diluted to near the concentration of standard solution and reanalyzed. The average of two corresponding peak heights, obtained from the mix-standard solution analyzed immediately prior to and after sample analysis, were used proportionally in calculating the concentrations of corresponding residues in the sample (Feng 1987; Feng and Feng 1988b; Feng, Feng, and Sidhu 1989).

5.7.2.5 Summary

The limit of quantitation of the analytical method was 0.03, 0.06, and 0.12 μg/g for hexazinone, metabolite B, and metabolite A, respectively. Recoveries of these three compounds were demonstrated at various concentration levels. The overall recovery for hexazinone was 94 ± 4%, when spiked at 0.03-6.25 μg/g; for metabolite B it was 93 ± 8% at 0.63-12.5 μg/g; for metabolite A it was 83 ± 19% at 0.25-25 μg/g. The data are summarized in Table 5-9. These recovery tests were conducted by adding known amounts of the compounds to the loamy clay with 10% organic matter contained in the 250-mL Nalgene bottle. Soil in bulk quantity was obtained prior to herbicide application in the Method II experimental areas of the Grande Prairie Vegetation Management Project.

Total amounts of solvents used in this method were 220 mL. It was less than 30% of amounts required in the conventional methods (Feng 1987; Feng and Feng 1988b; Holt 1981). Hexazinone and its metabolites A and B were not adsorbed on the column packing, therefore, the same solvent (methanol) can be used as extracting solution and eluent of the microcolumn. Since there was no need to change the solvent phase, the column eluting time was greatly reduced. Due to the simplicity of this method, 12-18 soil samples could be processed as one batch by one person in 1.5 days--three times more efficiently than conventional methods.

5.7.3 Microcolumn Method for Determination of Hexazinone in Vegetation

5.7.3.1 Sample preparation

Fresh or frozen fresh vegetation samples were used in this method for better extraction efficiency. Dry weight of the sample was determined from a separate aliquot of 10 g samples oven-dried at 105°C for 48 h. Foliage samples were cut to thin strips and grasses were cut into short sections by using a pair of scissors. Twigs were cut into very short sections (about 0.5 cm) before extraction.

5.7.3.2 Microcolumn preparation

See Section 5.7.1 above.

5.7.3.3 Sample cleanup

A 15-g aliquot of precut vegetation sample was weighed into a 250-mL Nalgene polymethylpentene centrifuge bottle (Nalge 2107). Exactly 60 mL of methanol were added to the bottle and samples were homogenized by using a Polytron PT-10 homogenizer for 2 min. The whole bottle content was filtered through a 47 mm Millipore assembly with 0.45 μm HVLP membrane and a 20-g bed of anhydrous sodium sulfate (Na_2SO_4 anhyd). The filtrate was collected in a 50-mL graduated conical centrifuge tube with Teflon-lined cap (60 mL total capacity). Exactly 30 mL aliquots of the filtrate (extracts of 7.5 g samples) were kept in the tube by removing the excessive amounts with a Pasteur pipet or aspiration. The extracts were partitioned five times with 25 mL of hexane and 30 s shaking each. The upper phase of hexane wash was discarded by aspiration. Exactly 25 mL of the lower methanol phase (extracts of 6.25 g sample) were retained by removing excessive amounts with Pasteur pipet or aspiration. The volume of sample was reduced to 5 mL with a stream of nitrogen in a N-Evap and then loaded on the dry-packed microcolumn with 3 × 0.5 mL methanol rinse of the sample tube. Methanol (15 mL) was also used as the eluent to elute hexazinone and its metabolites from the adsorbents of the microcolumn. All eluates were collected into a 15-mL

graduated conical tube and concentrated down to 5 mL by using nitrogen in a N-Evap. The sample was then partitioned with 4 × 10 mL of hexane and the upper phase (hexane) was removed with Pasteur pipet or aspiration. Only 4 mL of the lower methanol phase were retained in the tube and evaporated to dryness with nitrogen in a N-Evap (small amounts of oily residue may remain in the tube). Two mL of toluene (or predetermined volume between 1 and 10 mL depending on the predicted residue concentration) were added to the sample tube to redissolve residues before gas chromatographic analysis. A flow chart of this method is presented in Figure 5-7.

5.7.3.4 Gas chromatography

See Section 5.7.1 above.

5.7.3.5 Summary

The modified method of Holt (Feng 1987; Feng and Feng 1988b; Holt 1981) was tested by using aspen foliage samples. The end product showed a dense dark green color and high viscosity, which was impossible to analyze by capillary gas chromatography. Neither was the microcolumn method for soils described in Section 5.7.2 above able to remove chlorophyll. In this new method, hexane partition was introduced to remove chlorophyll from the methanol extracts both before and after microcolumn cleanup. Further cleanup was accomplished at the final step of the method by changing the solvent from methanol to toluene. The final product was either clear or pale amber color and produced a very clear chromatogram. Another point worth mentioning was that methanol seemed to cause fluctuating peak responses in the capillary gas chromatograph. Toluene provided excellent stability for the analysis but showed less solubility for some metabolites. Recoveries of hexazinone residues from fresh litter and four different vegetation species, i.e., reed grass, trembling aspen, showy aster, and willow are listed in Table 5-10. The limit of quantitation of the analytical method was similar to the soil method described in Section 5.7.2 above. The total amount of solvents needed per sample was 245 mL, and 12 samples could be processed as one batch by one person in 2 days.

EXTRACTION
20g homogenized soil sample
200 mL methanol
Shake 15 min
CENTRIFUGE
350 × g for 10 min
FILTRATION
Millipore assembly: 0.45 μm, HVLP 047 membrane
Collect 150 mL filtrate (for 15 g soil)
CONCENTRATION
To about 3 mL using Rotary Evaporator at 45°C
Quantitative transfer (3 × 2 mL methanol rinse)
into 15-mL tube; adjust final volume to 5 mL
MICROCOLUMN CLEANUP
1 mL Na_2SO_4 (anhyd) + 3 mL Al_2O_3 (neutral) + 3 mL Florisil
in a 10-mL disposable volumetric pipet
Load sample (5 mL) with 3 × 0.5 mL methanol rinse
Elute with 15 mL methanol
Collect all eluate (17 mL)
CHANGE SOLVENT PHASE
Evaporate to dryness by nitrogen
Redissolve in 2 mL toluene (or 1-10 mL)
GAS CHROMATOGRAPHY
The total soil weight used for residue calculation is 15 g

Figure 5-6. Flow chart of the microcolumn method for determination of hexazinone and metabolites A and B in soils.

Table 5-9. Mean (n = 3) and overall percent recoveries of fortified hexazinone, metabolites A and B in soil

Chemicals	Fortification Level (μg/g)	No. of samples	Mean recovery ± S.D. (%)
Hexazinone	0.03	3	92 ± 1
Metabolite B	0.06	3	80 ± 6
Metabolite A	0.12	3	48 ± 9
Hexazinone	0.06	3	91 ± 11
Metabolite B	0.12	3	95 ± 15
Metabolite A	0.25	3	62 ± 19
Hexazinone	0.12	3	102 ± 4
Metabolite B	0.25	3	102 ± 9
Metabolite A	0.5	3	72 ± 4
Hexazinone	0.63	3	92 ± 2
Metabolite B	1.25	3	90 ± 5
Metabolite A	2.5	3	79 ± 4
Hexazinone	1.25	3	91 ± 5
Metabolite B	2.5	3	89 ± 6
Metabolite A	5	3	90 ± 11
Hexazinone	6.25	1	96
Metabolite B	12.5	1	102
Metabolite A	25	1	111
Overall			
Hexazinone	0.03 to 6.25	16	94 ± 4
Metabolite B	0.06 to 12.5	16	93 ± 8
Metabolite A	0.25 to 25	13	83 ± 19

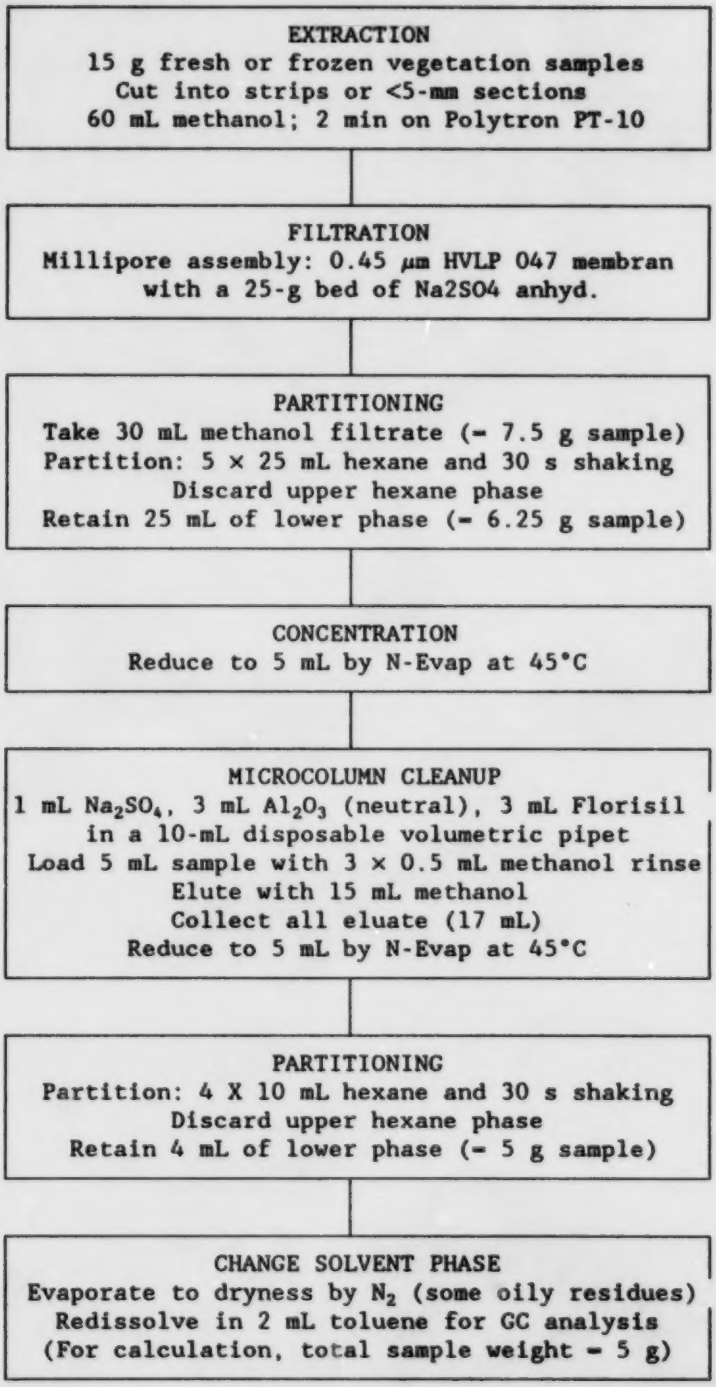
EXTRACTION
15 g fresh or frozen vegetation samples
Cut into strips or <5-mm sections
60 mL methanol; 2 min on Polytron PT-10
FILTRATION
Millipore assembly: 0.45 μm HVLP 047 membran
with a 25-g bed of Na2SO4 anhyd.
PARTITIONING
Take 30 mL methanol filtrate (= 7.5 g sample)
Partition: 5 × 25 mL hexane and 30 s shaking
Discard upper hexane phase
Retain 25 mL of lower phase (= 6.25 g sample)
CONCENTRATION
Reduce to 5 mL by N-Evap at 45°C
MICROCOLUMN CLEANUP
1 mL Na2SO4, 3 mL Al2O3 (neutral), 3 mL Florisil
in a 10-mL disposable volumetric pipet
Load 5 mL sample with 3 × 0.5 mL methanol rinse
Elute with 15 mL methanol
Collect all eluate (17 mL)
Reduce to 5 mL by N-Evap at 45°C
PARTITIONING
Partition: 4 X 10 mL hexane and 30 s shaking
Discard upper hexane phase
Retain 4 mL of lower phase (= 5 g sample)
CHANGE SOLVENT PHASE
Evaporate to dryness by N2 (some oily residues)
Redissolve in 2 mL toluene for GC analysis
(For calculation, total sample weight = 5 g)

Figure 5-7. Flow chart of the microcolumn method for determination of hexazinone and metabolites A and B in vegetation samples.

Table 5-10. Mean percent recovery of hexazinone spiked at 1 ppm (μg/g dry weight) in different vegetation species by using the microcolumn method

Species	Mean % recovery (n=2)
Reed grass (*Calamagrostis canadensis (Michx.)* Nutt)	92.3
Trembling aspen (*Populus tremuloides* Michx.)	76.1
Showy aster (*Aster conspicuus* Lindl.)	96.4
Willow (*Salix* spp.)	72.9
Fresh litter	81.5

Section 6

HEXAZINONE RELEASE AND ENVIRONMENTAL FATE

Hexazinone is a triazine herbicide that controls grasses and forbs for both preplant and postplant applications in the management of forest vegetation (Dimock et al. 1983; Malik and Vanden Born 1986). Although the environmental fate and impact of hexazinone has been investigated in water (Miller and Bace 1980; Neary 1983; Neary, Bush, and Douglas 1983; Neary, Bush, and Grant 1986), soil (Rhodes 1980a; Harrington, Rolston and Ivens 1982; Barring and Torstensson 1983), and living organisms (Rhodes 1980b; Rhodes and Jewell 1980; Mayack, Bush and Neary 1982) in the United States and elsewhere, limited published information (Feng 1987; Feng and Feng 1988a,b, 1989) is available for assessing hexazinone behavior in the forests of Canada. Environmental information from different locations in Canada as well as off-target drift information from aerial dispersal systems is required for its full forestry registration for aerial application in forested areas (> 500 ha) (Feng, Stornes, and Rogers 1988). Results of seven separate studies are reported, including the characteristics and release rate of surface-coated hexazinone from PRONONE 10G granules under both laboratory and field conditions and the dissipation, persistence, mobility, and leaching in soils, vegetation, soil leachates, and surface water.

6.1 RELEASE OF HEXAZINONE FROM PRONONE 10G GRANULES EXPOSED TO SIMULATED RAINFALL UNDER LABORATORY CONDITIONS[23]

6.1.1 Background

A new granular formulation of hexazinone, PRONONE 10G, is pending registration for forestry application in Canada. The use of the granular formulation is expected to minimize off-site drift mainly because of the large particle size (2-5 mm), heavier weight (20 mg), and nonvolatile nature of the formulation (Feng, Stornes, and Rogers 1988). The granules are made of a hard insoluble clay-base material and are surface-coated with 10% w/w hexazinone (a.i.). The granules are of irregular size and shape and are protected by an outer coating free of a.i. The protective coating minimizes dust formation and loss of hexazinone during shipping, handling, and dispersal. The active ingredient (ai), hexazinone, is released to the forest floor by the first available moisture, i.e., rain and dew, and percolates through soils as a concentrated column. The higher concentration of herbicide in a column form may facilitate root uptake compared with the broadcast application of a liquid formulation at the same rate. However, due to the increased concentration on spots where the granules land, a.i. persistence may occur with increased leaching. The behavior of the a.i. is further affected by its rate of release from the granule. The amount of moisture required to dissolve the protective outer coating and to release the a.i. is not known. This paper reports a simple and easy-to-operate apparatus to simulate rainfall and the release of hexazinone from the PRONONE 10G formulation.

---

[23]Feng, Stornes, and Rogers (1988).

6.1.2 Materials and Methods

The experimental work including procedure development and analysis was carried out by collaborators at the Pro-Serve laboratory in Memphis, Tennessee; while the study design, the major portion of data processing, and the manuscript preparation were done at the Northern Forestry Centre in Edmonton, Alberta.

6.1.2.1 Simulated rainfall apparatus and experimental procedure

The simulated rainfall apparatus (Fig. 6-1) consisted of a 1 L water reservoir and a simulated soil floor. The 1 L plastic reservoir was 9 cm in diameter with 40 holes (1.5 mm diameter) punched in the bottom in a circular pattern. A Tyler No. 60 sieve (20 cm diameter, 5 cm in height) with 0.25 mm openings was filled with 2.5 cm of all-purpose potting soil (bulk density = 0.64 kg/L) to simulate the surface soil in the field. A disk-type coffee filter (20 cm diameter) was placed on the soil surface to provide a flat surface, to allow water to percolate into the soil, and to avoid contamination of granules from the splashing of wetted dirt. The water reservoir was clamped onto a buret stand 20 cm above the simulated soil floor to allow an even coverage of water.

The PRONONE 10G granules used for testing were size selected within 4 to 6 U.S. standard mesh (3.35 to 4.75 mm openings) from a 10 kg lot of the regular formulation ranging from 4 to 10 U.S. standard mesh (2.0 to 4.75 mm openings). A total of 24 aliquots of 50 granules were randomly sampled in pairs (12 pairs of aliqouts) from the selected lot and weighed separately. A total of 1200 granules weighing 24 g were sampled in this study. One aliquot of a pair was designated as the control. The other was subjected to the a.i. release test and transferred into the simulated rainfall apparatus. Granules subjected to treatment were placed, without touching each other, evenly on the simulated soil floor by using a pair of forceps. Water was allowed to flow under gravity through the reservoir and rinse the granules. The flow rate was calibrated by adding water to the reservoir so that it percolated through the soil rather than submerging the granules. Three levels of simulated rainfall at 1.3, 2.5, and 5.1 cm, respectively were examined in 4 replicates. The total volume of water and time required to provide the specific amount of rainfall was calculated and is shown in Table 6-1. After rinsing was complete, granules were recovered and dried in a convection oven at 80°C for 24 h. Total hexazinone residues from the controls and those remaining on the treated granules (50 each) were extracted and quantified by gas chromatography (GC). The weight of hexazinone recovered from both control and treated aliquots was standardized as milligram of hexazinone per gram of granules (mg/g).

6.1.2.2 Standard and extracting solutions

The internal standard (ISTD) solution was made by dissolving 5.0 g of diphenylphthalate in 1 L of dichloromethane (0.5% w/v). A range of concentrations of analytical reference standard (ASTD) solutions were prepared by dissolving proper amounts of hexazinone (analytical grade 99.9% pure) into 50 mL of ISTD solution. The ASTD solution with a concentration closest to that of a sample solution (estimated by an initial GC analysis) was used for the quantification of the hexazinone residues in the sample. The ISTD solution was also used as the extracting solution during the sample preparation.

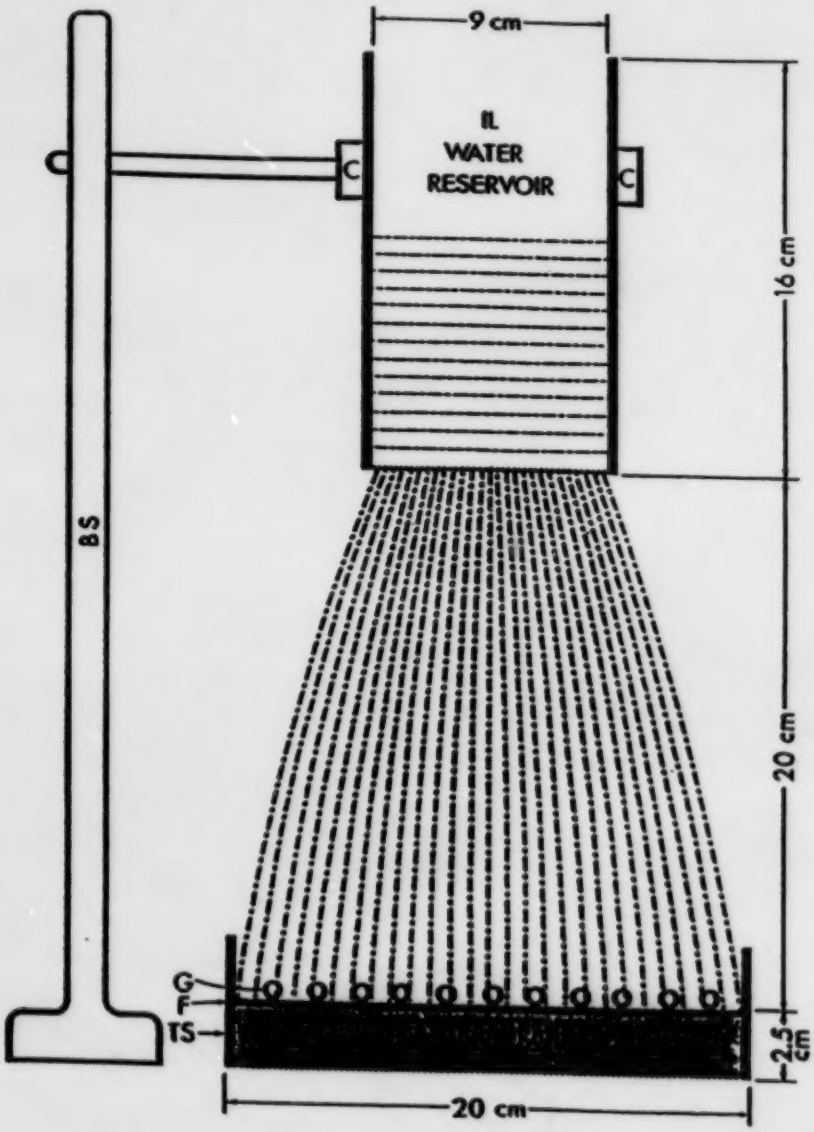

Figure 6-1. Schematic illustrating the simulated rainfall apparatus for testing the release of surface coated hexazinone (ai) from the PRONONE 10G granular formulation: (G) granules; (F) filter paper; (TS) Tyler No. 60 sieve; (C) clamps; (BS) buret stand.

Table 6-1. Volume of water and time required for the simulated railfall tests

Tested railfall level (cm)	Total volume of water required (mL)	Time period of tests (min)
1.3	400	15
2.5	800	30
5.1	1600	60

6.1.2.3 Sample preparation

The control and treated granules were ground separately in a grinding mill until all material passed through a U.S. 40 mesh screen (0.425 mm openings). The pulverized sample was transferred into a bottle containing 50 mL ISTD solution and shaken on a mechanical shaker for 5 min and then was allowed to settle. The supernatant was separated from the settled particles and analyzed by a GC.

6.1.2.4 Gas chromatography

The Hewlett-Packard Model 5840 gas chromatograph equipped with a FID detector and an integrator was used. The chromatographic column was 10% OV-7 on 100/120 mesh Gas Chrom Q; 60 cm glass; 2 mm inside diameter; 6 mm outside diameter; conditioned for 24 h at 240°C with carrier gas flow before use. The specific gas chromatographic conditions were as follows:

Temperature: Injector, 250°C; Column, 240°C; FID, 300°C.
Gas Flow Rates: N_2, 30 mL/min; Air, 240 mL/min; H_2, 30 mL/min.

6.1.3 Results and Discussion

Results of the simulated rainfall release of hexazinone from the PRONONE 10G granules are shown in Table 6-2. The percent release of hexazinone (Table 6-2) was calculated by the equation:

$$\% \text{ Release} = 100 \times (W_c - W_t) / W_c$$

where W_c = weight of hexazinone (mg/g granules) of the control aliquot calculated from 50 granules each, W_t = weight of hexazinone (mg/g granules) of the treated aliquot.

The percent ai released from 1.3 cm rain treatment ranged from 59.1% to 70.7% with an average of 65.5% ± 5.7% (8.7% CV); that from the 2.5 cm rain treatment, between 85.0% and 90.1% with an average of 87.4% ± 2.5% (2.9% CV); and that from the 5.1 cm rain treatment, between 84.8% and 95.9% with an average of 91.5% ± 4.9% (5.4% CV). It is evident from the results that 90% release of hexazinone from PRONONE 10G granules can be expected with 2.5-5 cm of rainfall. In Alberta this amount of rainfall would normally occur within 15-30 d in the month of September, the recommended period for hexazinone use in forest vegetation management. However, the testing conditions in this laboratory study may be considered as the worst-case condition, i.e., rainfall was simulated and applied on a continual basis with a 15-60 min completion time. These conditions did not permit a prolonged period for soaking, wetting, and dissolving of the coating material and ai. The

amount of water required for the a.i. release was, therefore, the highest (the worst-case condition). Under field conditions, small intermittent amounts of rainfall and overnight dew may slowly work into the protective coating and break the a.i. layer loose. Thus, the cumulative rainfall over a period of days or weeks required for 90% or more a.i. release could be significantly less than 5 cm found in this study. Field tests must be performed in order to assess the actual release rate of hexazinone from the PRONONE 10G granules in a forest environment. However, results of this study suggest that during a field study intensive sampling must be conducted immediately after application and before 2.5 cm rainfall is recorded.

Table 6-2. Total weight (mg) of hexazinone (a.i.) per g of granules and the calculated percent (%) a.i. release from PRONONE 10G formulation treated with simulated rainfall (cm).

Simulated rainfall treatment replication	Total weight[a] of hexazionone (mg/g)		Calculated percent release of hexazinone (%)		
	Control	Treated	% release	Mean ± S.D.	(CV)
1.3 cm rain					
	1 103.4	42.3	59.1		
	2 88.1	33.1	62.4	65.5 ± 5.7	8.71
	3 94.8	27.8	70.7		
	4 96.7	29.1	69.9		
2.5 cm Rain					
	1 112.1	11.1	90.1		
	2 116.7	13.0	88.9	87.4 ± 2.5	2.91
	3 100.5	15.1	85.0		
	4 110.7	16.1	85.5		
5.1 cm Rain					
	1 152.0	13.8	90.9		
	2 111.6	16.9	84.8	91.5 ± 4.9	5.41
	3 96.9	5.4	94.4		
	4 95.7	3.9	95.9		

[a] Calculated from 50 granules each.

The total weight of 50 PRONONE 10G granules, their hexazinone content and percent ai are shown in Table 6-3. The total weight of 50 granules ranged from 919.6 to 1327.9 mg with an average of 1044.7 ± 114.7 mg (n = 12; 11.0% CV). The average weight of 600 individual granules was 20.9 mg and similar to that (20 mg) measured by Feng and Sidhu (1989) on a 10 kg lot of regular PRONONE 10G formulation. The weights of hexazinone of 50 granules ranged from 91.2 to 148.9 mg with an average of 111.2 ± 19.3 mg (n = 12; 17.4% CV). Results of the *t*-test suggest that there was no significant difference between the weight variation of granules and their hexazinone content,

Table 6-3. Measurements and variations of the PRONONE 10G granule weight (mg), hexazinone weight (mg) and the percent (%) hexazinone content

Replication	Total Weight[a] (mg)		
	Granules	Hexazinone	% Hexazinone
1	1327.9	148.9	11.21
2	1142.4	133.3	11.67
3	1114.1	105.6	9.48
4	1093.9	109.9	10.05
5	1050.6	101.6	9.67
6	1037.5	92.0	8.87
7	1009.5	111.7	11.06
8	983.0	95.2	9.68
9	979.6	101.3	10.34
10	952.8	91.2	9.57
11	925.1	140.6	15.20
12	919.6	102.6	11.16
Mean ± S.D.	1044.7 ± 114.7	111.2 ± 19.3	10.66 ± 1.67
CV	11.0 %	17.4 %	15.6 %

[a] Measured from 50 control granules selected between 4 and 6 U.S. standard mesh (3.35 and 4.75 mm, respectively).

when the weight of hexazinone was corrected by multiplying by a factor of 10. The percent hexazinone contents of PRONONE 10G ranged from 8.87% to 15.2% with an average of 10.66% ± 1.67% (n = 12; 15.6% CV), and was 6.6% greater than the label- specified ai content. These results indicate that the size selection process for granules did not have a negative impact on the representation of the simulated rainfall release study for the PRONONE 10G formulation. The large variation (15.6% CV) of hexazinone content found in the 12 control aliquots of 50 granules each (a total of 600 granules) indicates the existence of a practical problem, i.e., the necessity for a large sample size during a field study on the ai release. It is practically impossible to recover hundreds of granules from the forest floor at each scheduled sampling time to control the variation of hexazinone content. In order to reduce the samples to a manageable number in a field study, methods and techniques must be developed to inoculate individual granules with the exact amount of hexazinone and coated by a procedure similar to that of the PRONONE 10G formulation, to implant the spiked granules onto the forest floor, and then to locate them at the time of sampling.

6.2 DETERMINATION OF HEXAZINONE RESIDUES AND RELEASE FROM A GRANULAR FORMULATION UNDER FOREST CONDITIONS[24]

6.2.1 Background

The 10% hexazinone coated on the surface of PRONONE 10G granules is released to the forest floor by moisture and percolates through soils as a concentrated column similar to a fine- scale spot treatment (Prasad and Feng 1990). The concentrated column form may increase the potential of leaching through the soil profile. The behavior of the ai, including the time it requires to reach the rooting zone and its persistence in soils, is further affected by the time required to release the ai from the granule. A laboratory study on the release of hexazinone from PRONONE 10G granules by continuous sprinkling with water suggested that the maximumamount of water required for a 90% ai release was equivalent to 50 mm of continuous rainfall (Feng, Stornes, and Rogers 1988). The actual amount of moisture required to dissolve the protective outer coating and to release hexazinone under field conditions is not known. It is important to determine the rate of hexazinone release from PRONONE 10G granules in order to determine the persistence of the ai in the environment. However, methods are needed to standardize the a.i. per granule and to retrieve granules from the field (Feng, Stornes, and Rogers 1988). This paper reports a) methodologies to fortify, apply, and retrieve granules and to quantify hexazinone residues in a granular formulation, and b) the rate of release of the surface-coated hexazinone in relation to cumulative amounts of precipitation and resident time of granules on the surface of soil.

6.2.2 Materials and Methods

6.2.2.1 Experimental

The 50-ha study site is located 30 km south of Grande Prairie and 460 km northwest of Edmonton, Alberta. The site is within the white spruce-*Viburnum-Aralia* ecosystem association of west-central Alberta (Corns and Annas 1986). The site was harvested for aspen and softwood in the fall of 1983. The vegetation regrowth established on a 3-year-old cutover was dominated by aspen of 1 m average height. Six 1.5-ha plots were subjected to a multidisciplinary forestry trial and were

---

[24]Feng, Feng, and Sidhu (1989).

aerially treated with PRONONE 10G on August 28, 1986. Eighteen 5 × 5 m subplots for the hexazinone release study were equally distributed in six treatment plots, i.e., three subplots per plot. Thirty granules specially fortified and coated in the laboratory were randomly implanted on the forest floor within each subplot before the aerial application of the herbicide. Each implanted granule was covered by a 20 × 20 cm nylon mesh (1 mm openings) secured at the corners with 30-cm pigtail pins to prevent contamination from the aerial application and for easy identification and retrieval of granules. Granules deposited on the surface of the mesh were removed immediately after the aerial application was complete. A 5-cm diameter hole was cut in the center of the mesh to expose the implanted granule to the naturally available moisture. The implanted granules were randomly sampled from subplots at 1, 2, 3, 4, 7, 8, 13, 18, 34, and 37 days after exposure. The number of granules retrieved on each sampling date were 8, 18, 18, 9, 4, 21, 25, 5, 9, and 18 respectively, depending on weather and road conditions and available manpower. Daily precipitation at 0.25 mm increments was recorded with a tipping-bucket rain gauge (Sierra Model RG2501) and a battery-powered data logger.

6.2.2.2 Granule fortification and coating

The blank granules (free of hexazinone) and coating materials and methods, similar to those used in the commercial formulation, were supplied by the manufacturer (Pro-Serve Inc., Memphis, Tenn.). Six hundred granules larger than a 4-mm mesh-opening were selected from the regular lot for uniformity. The coating materials were protected by patent; therefore, they were designated as solutions A and B, and a powder material as compound C. Solution A and compound C contained hexazinone, whereas solution B applied as the outer protective coating was free of hexazinone.

The procedure for coating each granule with a known amount of hexazinone consisted of weighing 50.0 g of solution A into a 100-mL beaker and heating it slowly to 37.8°C in a water bath while stirring it with a magnetic stirrer. Compound C (13.9 g) was dissolved slowly into solution A with stirring and heating. The 100-mL beaker was covered with a watch glass to prevent concentration changes due to evaporation. A 3-μL aliquot of this solution containing 1000 μg of hexazinone was applied to the surface of each granule by a 10-μL large bore HPLC syringe. The coated granules were allowed to dry at room temperature overnight. A 3-μL aliquot of solution B was then applied to the dried granules to serve as a protective coating and was allowed to dry at room temperature for 7 days. Six 100-granule batches were processed over a 6-day period. Each batch of granules was packaged separately. Two 3-μL aliquots of the coating solution were sampled at the time of preparing a batch of granules. Aliquots were analyzed by gas chromatography (GC) to confirm the actual concentration of hexazinone. Ten granules from each batch were also randomly sampled for the validation of the extraction method and for determining the weight of hexazinone per granule. The average a.i. of ten granules served as the initial a.i. per granule of each batch for later calculations of the percent release of a.i. from the granules.

6.2.2.3 Residue extraction and sample preparation

Two methods of extraction were tested: a new method using ethylacetate and a frequently used method employing acetone-water (4:1, v/v) (Holt 1981; Feng 1987). The latter was used to validate the results of the former. The testing of the new method is briefly described as follows: glass-distilled ethylacetate was used for the extraction and dilution of hexazinone from granules. Two aliquots of four control granules randomly sampled from each batch of 100 granules (a total of 48 granules) were subjected to a recovery test. Each aliquot was extracted five times with 20-, 20-, 20-,

15-, and 15-mL of ethylacetate in a disposable glass vial (Kimble scintillation vials, 20-mL) by using a vortex mixer (Thermolyne Maxi-Mix) followed with 5 min sonication in a sonicator (Cavitator Ultrasonic Cleaner, Mettler Electronics). The extracts were pooled with a 10-mL ethylacetate rinse of granules in the glass vial. The total volume of extracts was adjusted to 100 mL in a volumetric flask. An aliquot of the combined extracts was diluted four times with ethylacetate to about 2.5 g a.i./mL, and quantitated by GC. The remaining granules were further extracted twice with 20 mL ethylacetate and HPLC grade water, respectively, by 15 min of shaking and 15 min sonication. Each fraction of extracts was collected separately. The aqueous fraction was partitioned thrice with 20 mL ethylacetate each. The ethylacetate phases, separated from aqueous phases, were pooled and concentrated to 20 mL on a rotary evaporator under reduced pressure. The final 20 mL solutions of both fractions were analyzed by GC to confirm the completeness and efficiency of the first five extractions described above. Each granule collected from the field was extracted five times and rinsed once using a total of 100 mL ethylacetate as described above. The quantity of hexazinone per granule was determined by GC. The percent release of hexazinone per granule was obtained from the difference between the initially coated amount and that detected on the retrieved granule, expressed as a percentage.

6.2.2.4 Gas chromatography

The Varian Model 3500 Capillary GC equipped with a Thermionic Specific Detector (TSD) and a Model 8035 Autosampler was used. The chromatographic column was a 30-m J & W fused silica DB-17 column; 0.325 mm inside diameter; 0.25 μm film thickness. The specific gas chromatographic conditions were as follows: 1) Temperature: injection port, 250°C; detector, 300°C; oven temperature program, 50°C (1 min) - 250°C (30°C/min) - 280°C (15°C/min, 10.4 min) (total run-time = 20 min). 2) Gases (Liquid Carbonic, Edmonton, Alberta): carrier gas, helium (Ultra Pure grade) 4.3 mL/min at 50°C; linear velocity, 57 cm/s at 50°C; head pressure, 110 kPa; make-up gas, nitrogen (Ultra Pure grade) 30 mL/min; plasma gases, air (Zero Gas grade) 175 mL/min, hydrogen (Ultra Pure grade) 4.5 mL/min. Hexazinone peak heights were integrated by a Varian Model 604 High Performance Data System and were quantitated by comparison with the average peak height from the analytical grade hexazinone standard solution analyzed immediately prior to and after each sample analysis (Feng 1987).

6.2.3 Results and Discussion

6.2.3.1 Extraction methods

Both extraction methods, ethylacetate and acetone-water, produced similar recoveries for hexazinone; however, the acetone-water method (Holt 1981; Feng 1987) is labor intensive and requires more processing by evaporation, liquid-liquid partition and solvent phase transformation, and as a result is less productive. Results of the new ethylacetate method are presented in detail in this paper.

The extraction method using a total of 100 mL ethylacetate resulted in greater than 99.5% (14.6% CV.) recovery of hexazinone from 48 control granules spiked with an average of 1000 μg ai per granule. Less than 0.5% of residues were found in the subsequent extraction with 20 mL ethylacetate and prolonged sonication of 15 min. No residues were detected following extraction with 20 mL water and 15-min sonication. The detection limit of this method was 0.25 g ai per granule (0.025% ai of a control granule). The method of extraction of hexazinone was further evaluated by

using eight granules from the commercial formulation. The recovery of hexazinone was 94.3% (26% CV.) compared to the label a.i. content.

The concentration of hexazinone in the coating solution increased over time from 310 to 390 g/L due to evaporation by heating over the 6-day period of the coating process. Hexazinone contents (percent a.i.) of field samples were calculated based on that of their initial batches (as 100%), rather than on an overall average of six batches, in order to control the batch variation.

6.2.3.2 Hexazinone release

The release of hexazinone from the granules is triggered on the first occurrence of any amount of moisture (rain, dew, condensation). In the present case, 25.5% hexazinone release was etected 1 day after exposure to a rain event measuring 0.25 mm (Table 6-4). Even in the absence of any rainfall after the first day the release of hexazinone increased to 31.2 and 35.8% respectively, after 2 and 3 days of exposing granules to the conditions at the soil surface (Table 6-4). It was evident that in addition to rainfall, overnight condensation of moisture in the air as dew contributed significantly to trigger the release of hexazinone from the granules under field conditions. Visual observation in the field on individual granules and the released amount of hexazinone detected from each granule

Table 6-4. Percent hexazinone release from PRONONE 10G granules in relation to cumulative rainfall (mm) and exposure time (days)

Exposure time [a] (days)	No. of granules	% Hexazinone release			Cumulative rainfall (mm)
		Mean [b]	SE	% CV	
1	8	25.5	22.5	88	0.25 [c]
2	18	31.2	25.4	81	0.25
3	18	35.8	36.3	101	0.25
4	9	44.0	19.7	45	0.51
7	4	90.6	1.7	1.9	11.69
8	21	98.0	1.8	1.8	11.94
13	25	99.5	0.9	0.9	12.19
18	5	99.7	0.4	0.4	26.16
34	9	100.0	0	0	103.61
37	18	100.0	0	0	106.15

[a]Date of application: 28 August 1986.
[b]Detection limit: 0.025%.
[c]The minimum detectable rainfall by Sierra RG2501 tipping bucket rain gauge.

showed that granules shaded from direct contact with dew by leaf litter and organic debris resulted in slower release than in the granules directly exposed to dew. The release of hexazinone was increased to 44% when the second rainfall (0.25 mm) occurred on the 4th day after application (Table 6-4). The large variation (45% to 101% CV.) detected in hexazinone release during the first 4 days of exposure was probably due to a) the extremely small amount of rainfall (0.5 mm total), which was not capable of dissolving the ai evenly from granules, and b) the variation in the degree of exposure of individual granules on the forest floor. As a result, variable amounts of moisture condensed near or on the surface of granules.

A 90.6% release of hexazinone was found 7 days after exposure with 11.7 mm of cumulative rainfall (Table 6-4). An earlier laboratory study showed that an equivalent of 51 mm of continuous rainfall was required to achieve a 91.5% release of hexazinone from the granules (Feng, Stornes, and Rogers 1988). Less than 25% of the amount was required under field conditions to achieve a similar level of a.i. release.

The release of hexazinone was virtually complete after 8 days. The a.i. release was 98.0, 99.5, and 99.7% after 8, 13, and 18 days exposure, with 11.9, 12.2, and 26.2 mm of cumulative rainfall (Table 6-4). No detectable residues of hexazinone were found after 34 and 37 days when cumulative rainfall reached 104 and 106 mm.

The extraction and gas chromatographic method used in this study was capable of detecting and quantifying four major degradation products of hexazinone simultaneously (Holt 1981; Feng 1987). None of these degradation products was found in the field samples, which indicated that the hexazinone was released intact to the forest floor. The full amount of hexazinone residues released from the granules were detected in soil samples collected to a 10-cm depth immediately underneath the granule in a 10-cm diameter soil disk 1 day after application (Feng and Feng 1988a).

The kinetics of hexazinone release are best described by a multiple linear regression of log transformation of three variables: the percent ai (y), days of exposure (x_1), and the cumulative rainfall (mm) (x_2).

$$\log (y) = b_o + b_1 \log (x_1) + b_2 \log (x_2)$$

Data on days of exposure, cumulative rainfall, and the average value of percent a.i. at each sampling date were used to obtain the intercept (b_o = 1.83) and the partial regression coefficients (b_1 = -0.966; b_2 = -0.620). The corresponding percent release was the difference between 100% and percent ai The result of the F-test for the multiple regression was significant (P = 0.01). The coefficient of multiple regression determination (R_2) indicated that the regression equation accounted for 89% of the variation in the data. The significant multiple correlation coefficient (R) indicated that data values fitted very closely to the regression line (R = 0.94). The standard partial regression coefficients (b_1' and b_2') for x_1 and x_2 were 0.42 and 0.57. Though both of these variables were useful in estimating y, x_2 was slightly more important. Based on the standard partial regression coefficients, the relative contributions of x_1, x_2, and error to the overall regression were 37, 51, and 12% in this case (Steel and Torrie 1960).

Estimates were derived from the multiple regression to correlate days of exposure required to achieve the release of hexazinone between 50 and 90% at 10% increments with a known amount of cumulative rainfall at seven different levels between 0.25 and 25 mm (Table 6-5). A 90% release of hexazinone may be expected 1, 2, 3, 4, 7, 14, and 21 days after application with 25, 10, 5, 2.5, 1.0, 0.5, and 0.25 mm of cumulative rainfall, respectively (Table 6-5). Under field conditions, the relative

humidity, difference between day and night temperatures, and other microclimatic conditions at the granule-soil interface are important variables for dew formation near the granular surface. During the course of this study, the average relative humidity was 53 ± 22 % (at 4 p.m.), the average daily low air temperature was 5 ± 5°C (at 7 a.m.), and the daily high was 16 ± 6°C (at 4 p.m.). These weather conditions are typical of spring and fall in northern Alberta. The spring and fall are the recommended times for hexazinone application based on the registration information. Longer exposure time should be allowed for the expected percent release of hexazinone when the relative humidity is low and the difference in air temperature between daily high and daily low is small.

Table 6-5. Estimation of the expected days required on the percent release of hexazinone from the PRONONE 10G granules by cumulative rainfall

Cumulative rainfall (mm)	Hexazinone release (days)				
	50%	60%	70%	80%	90%
0.25	3	4	7	14	21
0.50	2	3	4	7	14
1.0	1	2	3	4	7
2.5		1	2	3	4
5.0			1	2	3
10.0				1	2
25.0					1

6.3 HEXAZINONE RESIDUES AND DISSIPATION IN SOIL LEACHATE[25]

6.3.1 Background

Registration of herbicides for forestry use in Canada has a focus on environmental safety as well as efficacy. The herbicide hexazinone has a potential use in forest vegetation management and received temporary registration for ground application in 1984, with the proviso that terrestrial and aquatic fate data for Canadian conditions would be needed before a full forestry registration could be granted (Feng 1987; Feng, Stornes, and Rogers 1988). The laboratory-generated models for predicting the herbicide movement and fate in ecosystems require validation under field conditions (Neary et al. 1983). Hexazinone, being soluble in water (3.3%, w/w) (WSSA 1983), has the potential for lateral and downward movement. Barring and Torstensson (1983) found that hexazinone moved

[25]Feng, Sidhu, Feng, and Servant (1989).

with water at least 2 m down a 12-22 degree slope. In another study, the lateral movement was not detected 20 m downslope on a 5-10% gradient (Feng 1987). In a stream directly treated with hexazinone pellets, waterborne hexazinone decreased to less than half of the initial concentration within 1 hour after application at a point adjacent to the treated area (Miller and Bace 1980). Neary, Bush, and Douglass (1983) and Neary, Bush, and Grant (1986) reported in a study monitoring stormflow and baseflow through 26 storm events over a 13-month period that an estimated 0.53% of the hexazinone applied was lost through runoff; in another study, Neary (1983) found no residues in groundwater and springflow beyond 20 m from the treated area. The potential leaching of hexazinone through soil-free water directly under the treated area has not been studied. This paper reports hexazinone residue levels in the soil leachates collected at 30-, 55-, and 80-cm depths from areas treated with 0, 20, and 40 kg/ha PRONONE 10G (10%, w/w, hexazinone) over a 448-day period.

6.3.2 Materials and Methods

6.3.2.1 Experimental site and herbicide application

The 5-ha study site is located 30 km south of Grande Prairie, Alberta. The site is within the white spruce-*Viburnum-Aralia* ecosystem association of west-central Alberta (Corns and Annas 1986). The site was a 3-year-old regrowth from a forest clear-cut in July 1983. The regrowth was dominated by aspen with an average height of 1 m. Duff and organic cover was less than 5 cm. The soil was gleyed solonetzic dark gray to gray luvisol, stone free, and was silty clay (at upper and middle depths) to clay (at middle depths) in texture.

Three 1.6-ha plots (2% slope) were treated with 0, 20, and 40 kg/ha PRONONE 10G (0, 2, and 4 kg ai/ha), a granular formulation containing 10% (w/w) surface-coated hexazinone (ai) (Pro-Serve Inc., Memphis, Tenn.). The herbicide was applied on 28 August 1986 by a helicopter equipped with an Isolair Series 2600-45 Applicator-Spreader.

6.3.2.2 Soil leachate collection

An open-end trench (13 m long × 1.25 m wide) was dug with a backhoe at the end of each treatment plot (7% slope). Three horizontal tunnels (45 cm in length × 5 cm in diameter) were prepared using a coring drill at depths of 30, 55, and 80 cm from the cut face of the plot (Fig. 6-2). Each tunnel was installed with a PVC pipe 60 cm in length and 5 cm in diameter. A 45-cm perforated section of the pipe acted as a soil leachate collector. Grouting was used to plug the gap between the drilled hole and PVC pipe. A 500-mL narrow-mouthed plastic bottle was attached at the sealed end of each PVC pipe (Fig. 6-2). The cap of the plastic bottle was plastic-welded onto the PVC pipe with a hole drilled through both cap and pipe to allow the soil leachate collection in the removable plastic bottle (Fig. 6-2).

There was no, or an insignificant, volume of soil leachate in the collection bottles up to 112 days after PRONONE application and before ground freeze-up. The volumes were too small to analyze individual samples separately or even collectively for residues from each of the three depths. The first collection for residue analysis was made at 227 days (12 April 1987) after application following snowmelt. The later collections were made following major rain events up to 448 days (19 November 1987) after the herbicide application.

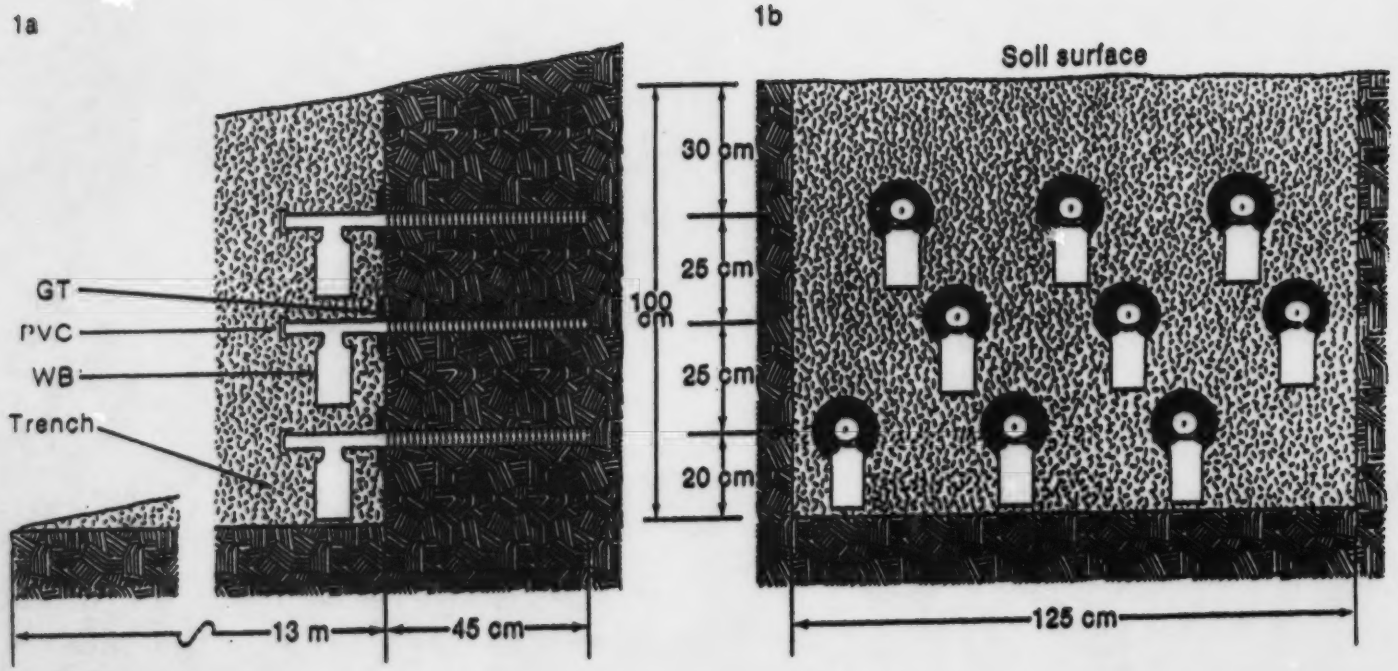

Figure 6-2. Cross Section (1a) and Front View (1b) of Soil Leachates Collector GT: Grouting; PVC: PVC Pipe, 60 x 5 cm Perforated with 1-cm Opening at 7-cm Spacing; WB; 500-mL Narrow Mouth Plastic Water Bottle.

Bottles with soil leachates were replaced with fresh bottles at each time of collection. Collected samples were frozen immediately at -5°C and stored for 1-2 weeks before shipping to the analytical laboratory, where they were stored at -20°C for 1-2 months before analysis for hexazinone residues.

6.3.2.3 Residue analysis

The volume of each soil leachate sample was measured and then extracted three times with ethyl acetate (Feng and Feng 1988b). The ethyl acetate phases were pooled and evaporated to dryness in a 1-L round-bottom flask by using a rotary evaporator under reduced pressure. Residues were redissolved in 5 mL of methanol and quantitatively transferred by several rinses with small amounts of methanol into a 15-mL graduated tube. The final volume was reduced to 1.5 mL by using nitrogen in a N-Evap (Organomation Assoc. Inc., South Berlin, Mass.).

The gas chromatographic analysis and peak quantitation were similar to that reported earlier (Feng 1987). The specific gas chromatographic conditions were modified as follows:

Gas Chromatograph: Varian Model 3500 Capillary GC equipped with a Thermionic Specific Detector (NPD), a Model 8035 Autosampler, and a Hewlett-Packard Thinkjet printer-plotter.

Chromatographic Column: 30-m J&W fused silica DB-17 column; 0.325 mm inside diameter; 0.25 μm film thickness.

Temperatures: Injector, 250°C; detector, 300°C; oven temperature program, 50°C (2 min) - 250°C (30°C/min) - 280°C (15°C/min) (10.4 min); total run-time = 20 min.

Gases (Liquid Carbonic, Edmonton, Alberta): Carrier gas, helium (Ultra Pure grade) 4.3 mL/min at 50°C; linear velocity, 57 cm/s at 50°C; head pressure, 110 kPa; make-up gas,nitrogen (Ultra Pure grade) 30 mL/min; plasma gases, air (Zero Gas grade) 175 mL/min; hydrogen (Ultra Pure grade) 4.5 mL/min.

Retention time for hexazinone: 13.7 min.

6.3.2.4 Statistical analysis

Data collected from 227 to 448 days after treatment were analyzed by using the following multiple regression model:

$$W = A_0 + A_1V + A_2D$$

where W is the total hexazinone residues (μg) per depth (pooling of 3 bottles), V is the volume (mL) of leachates per depth (pooling of 3 bottles), and D is the elapsed time (days) since PRONONE 10G treatment.

6.3.3 Results and Discussion

Leaching of hexazinone was triggered by the snowmelt in the spring of 1987 and continued till the end of the monitoring period, between 227 and 448 days after PRONONE 10G treatment. Results of both 2 and 4 kg ai/ha treatments in terms of the volume of leachates (mL) and the concentration (ppb) and weight (μg) of hexazinone in the soil leachates between 227 and 448 days after treatment are shown in Figures 6-3 and 6-4.

In the 4 kg ai/ha treated plot, concentrations of hexazinone in the soil leachates collected at 30 cm depth increased from 162 ppb after 227 days (12 April 1987) to a peak of 492 ppb after 277 days (1 June 1987); concentrations then declined rapidly to 22 ppb after 448 days (19 November 1987) (Fig. 6-3, 2a). The concentration of hexazinone was inversely related to the volume of leachates (Fig. 6.3, 2b). The sample collected at 30 cm depth after 277 days had the highest concentration (492 ppb) but also the lowest volume (152 mL) compared with samples collected at the same depth but different times (Fig. 6-3, 2b). The simple regression of hexazinone concentration (ppb) on the volume of leachates and time from treatment showed very poor correlation with these two variables; however, the total weight (μg) of hexazinone in the soil leachates (Fig. 6-3, 2c) was strongly related to the volume (mL) of leachates as well as the time (days) since herbicide treatment. The total weight of hexazinone (μg) reached a peak of 205, 121, and 89 μg at 30, 55, and 80 cm depths, respectively, after 227 days (Fig. 6-3, 2c). Although, at 55 cm depth, hexazinone residues increased slightly to 178 μg after 264 days, hexazinone residues declined gradually with time to a minimum of 9, 11, and 3 μg at 30, 55, and 80 cm depths after 448 days. The regression equations as well as correlation coefficients (R) for the three depths and two rates of application are presented in Table 6-6. The correlation coefficients (R), 0.89, 0.70, and 0.88 for depths of 30, 55, and 80 cm were significant (Table 6-6). The partial regression coefficients (A_1 and A_2) for V and log D (Table 6-6) indicated that hexazinone leaching through soil water at any depth increased with the rate of soil water percolation (A_1) but declined over time (A_2).

Similar patterns of changes in concentration and volume as well as weight of hexazinone over time were observed in the 2 kg ai/ha plot but on an disproportionally smaller scale (Fig. 6-4). Hexazinone concentrations at 30 cm depth increased from 66 ppb after 227 days to a peak of 115 ppb after 271 days, then declined to 18 ppb after 417 days (Fig. 6-4, 3a). The peak concentration (115 ppb) was also associated with the lowest volume of soil leachates (71 mL) compared with other samples collected at the same depth (30 cm) but at different times (Fig. 6-4, 3b). The maximum weight of hexazinone residues (μg) found in the soil leachates of the 2 kg ai/ha treatment plot was less than one third that of the 4 kg ai/ha plot. Hexazinone residues peaked at 61, 26, and 39 μg at 30, 55, and 80 cm depths after 227 days (there was a second peak at 28 μg at 55 cm after 351 days); they then declined to 0, 4, and 17 μg after 448 days (Fig. 6-4, 3c). Correlation coefficients (R) were 0.94, 0.99, and 0.86 for depths of 30, 55, and 80 cm (Table 6-6).

The coefficient of determination (R^2) indicated the multiple regression accounted for 89, 98, and 75 percent of the variation in the data, respectively.

This study indicates that hexazinone can be transported to as deep as 80 cm through active soil-water percolation during snowmelt and heavy precipitation events; however, the concentrations of hexazinone found at the end of the monitoring period (448 days) were extremely low (maximum 0.5 ppm). Chakravarty and Sidhu (1987a) reported that hexazinone has no adverse effect on the *in vitro* mycelial growth of mycorrhizal fungi below 10 ppm. Compared with the tolerance level of wildlife and fish to hexazinone, LD_{50} and LC_{50} ranging from 5000 ppm to 274 ppm (WSSA 1983), the low

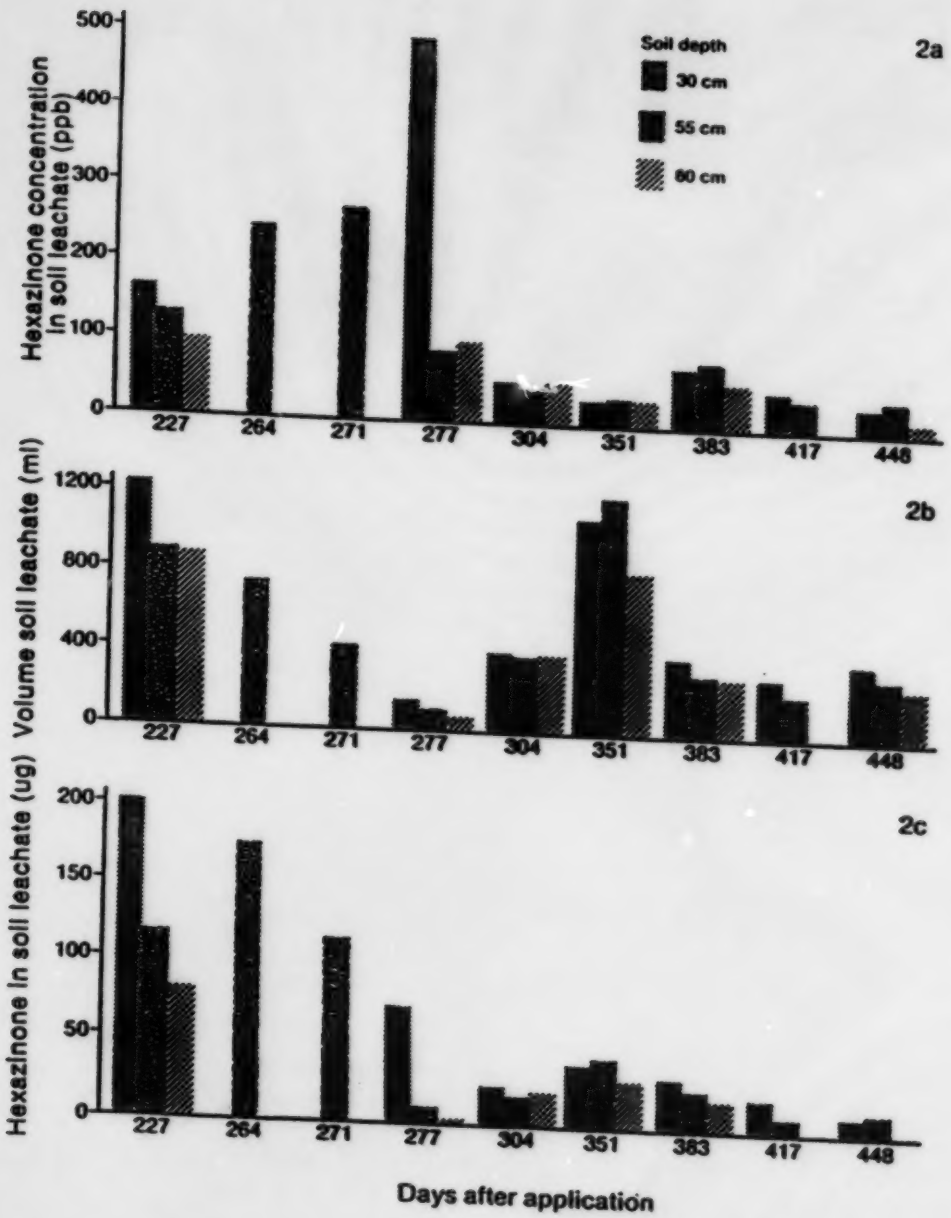

Figure 6-3. Hexazinone concentraion (2a), volume of soil leachates (2b) and total weight of hexazinone residues (2c) in soil leachates collected at different depths from the 4 kg ai/ha treated plot between 227 and 448 days after PRONONE 10G treatment.

Table 6-6. Equations illustrating leaching and dissipation of hexazinone in soil water by time and volume of leachates at different depths treated with two rates of PRONONE 10G

PRONONE 10G (kg/ha)	Soil depth (cm)	Equation[a]	R	N
20	30	W = 163 + 0.0466V - 65.8 logD	0.94	7
	55	W = 55 + 0.0252V - 22.0 logD	0.99	6
	80	W = 111 + 0.0260V - 42.8 logD	0.86	7
40	30	W = 1392 + 0.0378V - 536 logD	0.89	7
	55	W = 1070 + 0.0505V - 414 logD	0.70	9
	80	W = 411 + 0.0566V - 163 logD	0.88	6

[a] W = Ao + A1 V + A2 log D; W is the weight (ug) of hexazinone residues in soil water as estimated from the equation, D is number of days since treatment, and V is the volume (mL) of leachates collected at the time D. W and V were the total of three samples for each depth and each time of collection.

levels of residues resulting from this study should not pose any serious environmental hazard at the application rates studied.

6.4 PERSISTENCE AND MOBILITY OF HEXAZINONE IN SOILS[26]

6.4.1 Background

The validity of laboratory-generated models in predicting herbicide movement and persistence in ecosystems requires verification with systematic field evaluation (Neary et al. 1983). The persistence and mobility of hexazinone in soils was found to be dependent on soil type and climate. Field soil studies reported in the USA and elsewhere indicated that hexazinone has a half-life (or DT_{50}: time required for the dissipation of 50% residues) between 1 and 6 months (Rhodes 1980a; WSSA 1983) and the potential for off-site movement of at least 2 m down a 12-22 degree slope (Barring and Torstensson 1983; Harrington et al. 1982). A limited number of Canadian studies were conducted in New Brunswick, Ontario, and British Columbia for supporting the federal registration of hexazinone (Feng 1987; Feng and Feng 1988b; Roy, Konar, Charles et al. 1989).

From a 1-year field monitoring, hexazinone residues in New Brunswick loam showed a DT_{50} of 8, 28, and 13 days for upper (0-15 cm), lower (15-30 cm), and combined (0-30 cm) soil layers,

[26]Feng and Feng (1988a; 1989); Feng, J.C. (Unpublished data).

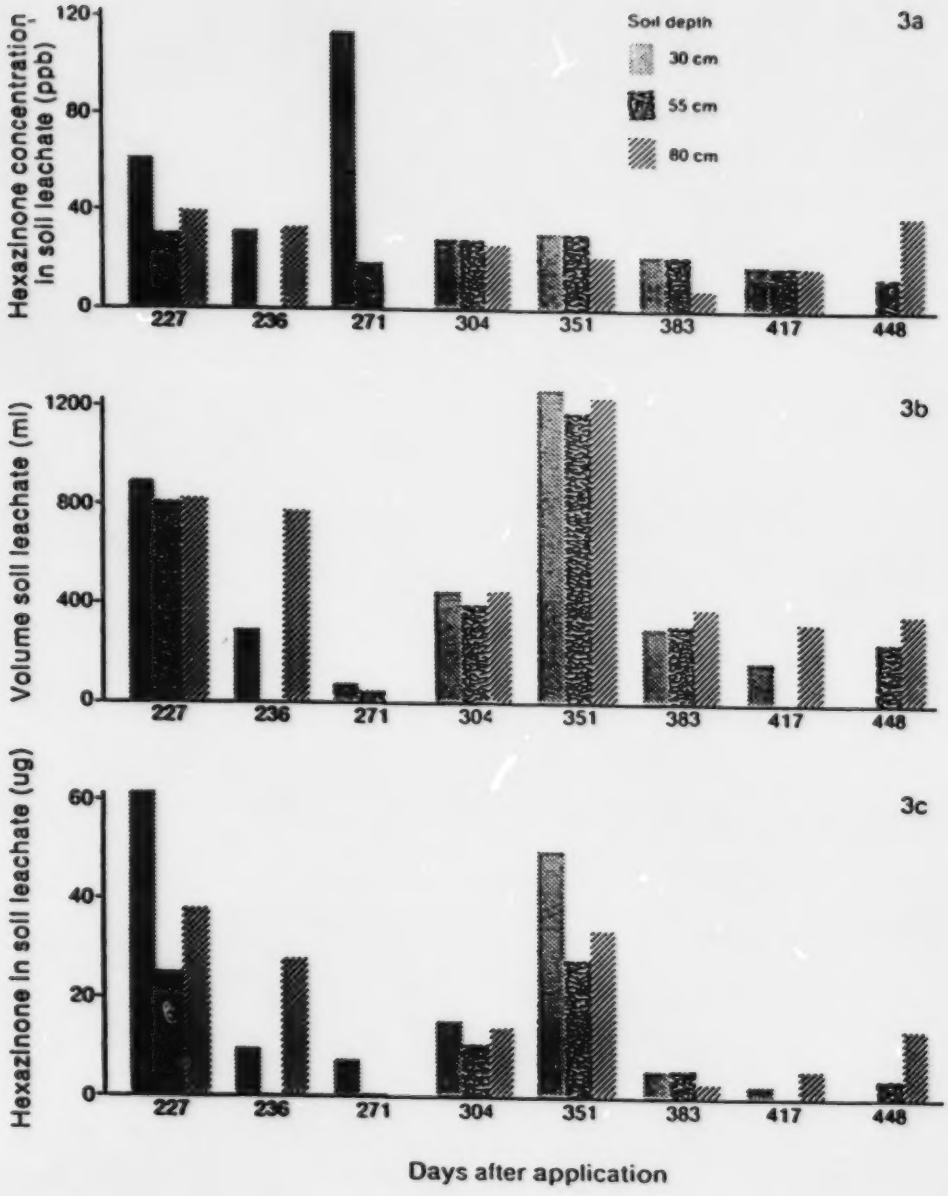

Figure 6-4. Hexazinone concentration (3a), volume of soil leachates (3b) and total weight of hexazinone residues (3c) in soil leachates collected at different depths from the 2 kg ai/ha treated plot between 227 and 448 days after PRONONE 10G treatment.

respectively (Feng and Feng 1988b); 43 days in both Ontario sand and clay, very limited potential to leach vertically through the soil column, and no evidence of lateral movement down the 7-8° slope (Roy, Konar, Charles et al. 1989). Hexazinone residues reduced rapidly to 40% within three weeks but persisted at similar levels to the end of the growing season (104 days after application) in the surface organic, but no residues were found in the underlying silt loam nor 20-40 m down a 5-10° slope in a British Columbia forest (Feng 1987). However, Feng and Campbell (1985) observed a large variation of hexazinone residues among the field samples during the initial soil samplings of Lamplugh (Ontario) clay when seven replications were employed. Similar observations were reported when soil samplings were replicated four and five times (Feng and Feng 1988b; Roy, Konar, Charles et al. 1989).

It was observed by the provincial operational foresters that some local runoff of hexazinone occurred when applied with a spotgun at concentrated spots in grid patterns either on wet areas or on hillsides. Similar to the spotgun treatment, Pronone 10G granules used in the Grande Prairie vegetation management project would act as mini concentrated spots when applied on the forest floor.

The dissipation pattern of herbicide at a high application rate might be different than at a lower rate. Although there is no supporting evidence, Canadian federal registration of forestry herbicides requires data on degradation in soils on two application rates, the highest rate stated on the label and the lowest possible effective rate. Field studies should be designed to evaluate this situation.

Questions such as the potential of vertical leaching, persistence, and field sampling variation must be answered when a new formulation of hexazinone (Pronone 10G) is to be used. With the improved sampling and analytical methods and maximum manageable replications, a reasonably well-established data base may be obtained in this study for addressing the above questions.

6.4.2 Materials and Methods

6.4.2.1 Site description

The 50-ha study site is located 30 km south of Grande Prairie and 460 km northwest of Edmonton, Alberta. The site is within the white spruce-Viburnum-Aralia ecosystem association of west-central Alberta (Corns and Annas 1986). The site was harvested for aspen and softwood in the fall of 1983. The vegetation regrowth established on a 3-year-old cutover was dominated by aspen of 1-m average height at the time of herbicide treatment.

6.4.2.2 Experimental design

Three treatment blocks consisting of six 1.5-ha plots were subjected to a multidisciplinary forestry trial. Two plots in each block were aerially treated with 20 or 40 kg/ha PRONONE 10G, on August 28, 1986. Eighteen 5 × 5 m subplots for the hexazinone persistence and vertical movement study were equally distributed in six treatment plots, i.e., three subplots per plot. Fifteen and 30 granules specially fortified and coated in the laboratory were randomly implanted on 15 spots on the forest floor within each subplot in the 20 and 40 kg/ha treatment plots before the aerial application of the herbicide. Each spot implanted with either one or two granules for 20 or 40 kg/ha treatment, was covered by a 20 × 20 cm nylon mesh (1 mm openings) secured at the corners with 30-cm pigtail pins to prevent contamination from the aerial application and for easy identification and soil sampling.

Granules deposited on the surface of the mesh were removed immediately after the aerial application was complete. A 5-cm diameter hole was cut in the center of the mesh to expose the implanted granule to the naturally available moisture. Soil cores were randomly sampled from one treatment spot per subplot (nine or 3 x 3 replications each for 20 and 40 kg/ha treatments) at 2, 4, 8, 13, 34, 61, 286, 321, 365, 399, 627, 680, and 767 days after implantation of spiked granules. Soil cores were taken with a 10-cm diameter Campbell auger (Feng and Klassen 1986) to a 42-cm depth and were sliced into 5 sections at depths of 0-10, 10-20, 20-30, 30-35, and 35-40 cm. The bottom sections of 40-42 cm, as the protective layer, were discarded to prevent cross-contamination. Daily precipitation at 0.25 mm increments was recorded with a tipping-bucket rain gauge (Sierra Model RG2501) and a battery-powered data logger, which also recorded hourly air temperatures and relative humidities, and soil moistures and temperatures at two depths.

6.4.2.3 Granule fortification and coating

The blank granules (free of hexazinone) and coating materials and methods, similar to those used in the commercial formulation, were supplied by the manufacturer (Pro-Serve Inc., Memphis, Tenn.). Six hundred granules larger than a 4-mm mesh-opening were selected from the regular lot for uniformity. The coating materials were protected by patent; therefore, they were designated as solutions A and B, and a powder material as compound C. Solution A and compound C contained hexazinone, whereas solution B applied as the outer protective coating was free of hexazinone.

The procedure for coating each granule with a known amount of hexazinone consisted of weighing 50.0 g of solution A into a 100-mL beaker and heating it slowly to 37.8°C in a water bath while stirring it with a magnetic stirrer. Compound C (13.9 g) was dissolved slowly into solution A with stirring and heating. The 100-mL beaker was covered with a watch glass to prevent concentration changes due to evaporation. A 3-μL aliquot of this solution containing 1000 μg of hexazinone was applied to the surface of each granule by a 10-μL large bore HPLC syringe. The coated granules were allowed to dry at room temperature overnight. A 3-μL aliquot of solution B was then applied to the dried granules to serve as a protective coating and was allowed to dry at room temperature for 7 days. Six 100-granule batches were processed over a 6-day period. Each batch of granules was packaged separately. Two 3-μL aliquots of the coating solution were sampled at the time of preparing a batch of granules. Aliquots were analyzed by gas chromatography (GC) to confirm the actual concentration of hexazinone. Ten granules from each batch were also randomly sampled to determine the weight of hexazinone per granule. The average weight of active ingredient from 10 granules served as the initial weight per granule for each batch for later calculations of the percent recovery of residues in soils sampled at different time periods.

6.4.2.4 Residue extraction, cleanup, analysis, and reporting

Soil core sections were prepared for extraction by weighing, air-drying (to less than 5% moisture content of oven-dried soils), homogenizing, and sieving (2 mm mesh) the soils as described by Feng and Klassen (1986). Total weights of fresh samples, air-dried samples, and pebbles (> 2 mm diameter, which were contained in the samples and discarded later) were measured. Sample air-dried weights were used to compute residue date from μg/g (weight) to kg/ha (area) bases (Feng and Klassen 1986).

Aliquots of soils were weighed, extracted, purified, and analyzed by a new microcolumn cleanup method and gas chromatographic method developed in this laboratory. Details of these methods are

reported in Section 5.7. Means and standard errors of each reatment rate at different time periods were calculated and the statistical model tested:

$$Y = aX^bc^X$$

or

$$\log Y = b_0 + b_1 \log X + b_2 X$$

6.4.3 Results and Discussion

PRONONE 10G granules contain bulk 10% hexazinone surface-coated on an insoluble base material. However, granules are of irregular shapes and vary in sizes. Granule weight ranges from 2.5 to 93 mg with an average of 20 mg and 35% CV (n = 315) (Feng and Sidhu 1989). For a given weight, smaller granules would result in greater numbers with larger total surface area delivering a larger amount of hexazinone to the target. Therefore, granules must be fortified with similar amounts of hexazinone, regardless of their shapes, to provide a reasonable baseline for initial amount of residues. As reported earlier (Feng, Feng, and Sidhu 1989), the concentration of hexazinone in the coating solution increased over time from 310 to 390 μg/mL as a result of evaporation by heating over the 6-day period of the coating-fortification process. Calculation of the hexazinone content (percent active ingredient) of field samples was based on that of the initial batches and that recovered from the exposed granules as 100%, rather than on an overall average of six batches, to control batch variation.

Hexazinone dissipated rapidly from the initial amount applied (100%) to 18% and 15% in the top 10-cm soil layer in the 2 and 4 kg ai/ha treatment plots, respectively, 61 days after application (Tables 6-7 and 6-8). Small amounts of hexazinone (0.1-4%) leached from the top layer (0-10 cm) to the next deeper layer (10-20 cm) when about 12 mm of rainfall occurred 8 and 13 days after application in both 2 and 4 kg ai/ha treatments. Major hexazinone movement was triggered by a 100-mm rainfall 37 days after application. The distribution profiles of hexazinone residues in the 0-10, 10-20, 20-30, 30-35, and 35-40 cm layers were 30, 13, 4.8, 0.8, and 0% in the 2 kg ai/ha treatment and 27, 17, 7.4, 1.4, and 0% in the 4 kg ai/ha treatment (Tables 6-7 and 6-8). Hexazinone leaching to the 35-40 cm soil layer occurred 1 year after treatment at very low level between 0.5 and 0.3% in 2 and 4 kg ai/ha treatments, respectively. Total combined residues of all layers (0-40 cm) were reduced to 34-39% at the end of the first year (1986), 14-16% the second year (1987), and 3-5% the third year (1988) (Tables 6-7 and 6-8).

Large variations of hexazinone residues between 7 and 70% CV were observed among each nine replicated samples during the first 2 months of sampling in both 2 and 4 kg ai/ha treatments (Tables 6-7 and 6-8). Comparing with the results of earlier studies where four to seven replicates were employed (Feng and Campbell 1985; Feng and Feng 1988b; Roy, Konar, Charles et al. 1989) an increase to nine replicates as in this study did not seem to improve field sampling variation.

Both metabolites B and A were present in similar pattern and in accordance with hexazinone but at relatively much smaller quantities. Metabolite B was found in most samples collected from the 0-10 cm layer at low level except 13 days postapplication, which showed 10.3 and 5.4% equivalent to 2 and 4 kg/ha of hexazinone applied, respectively (Tables 6-9 and 6-10). Although metabolite B was found to be only 1% as phytotoxic as its parent compound hexazinone (Sung et al. 1985), the presence of this metabolite as a percentage of its parent compound in the deeper soil layers, 30-35 and 35-40 cm, indicated the ongoing degradation of hexazinone through a demethylation process under perhaps anaerobic conditions. The presence of the nonphytotoxic metabolite A (Sung et al.

Table 6-7. Dissipation and leaching of hexazinone applied as Pronone 10G (2 kg ai/ha) in Grande Prairie soils (1986 - 1988)

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	88 ± 27	0	0	0	0	88	0.25
Sep 01	4	82 ± 27	0	0	0	0	82	0.51
Sep 05	8	59 ± 30	0.1 ± 0.1	0	0	0	59	11.7
Sep 10	13	47 ± 33	4.2 ± 6.8	0	0	0	51	12.2
Oct 04	37	30 ± 23	13 ± 6	4.8 ± 2.9	0.8 ± 1.4	0	49	106
Oct 28	61	18 ± 9	11 ± 6	3.9 ± 6.0	1.0 ± 1.2	0	34	110 (snowfall 95.3 cm)
1987								
Jun 10	286	13 ± 7	4.6 ± 3.7	3.3 ± 3.0	2.0 ± 1.9	0	23	44.3
Jul 15	321	7.5 ± 2.0	4.0 ± 1.7	2.0 ± 2.0	0.7 ± 0.4	0	14	129
Aug 28	365	5.8 ± 2.6	4.1 ± 1.8	1.3 ± 1.0	0.7 ± 0.6	0.5 ± 0.5	12	272
Oct 01	399	5.3 ± 1.8	5.8 ± 4.2	3.0 ± 2.2	0.7 ± 0.6	1.5 ± 1.1	16	285 (snowfall 119.4 cm)
1988								
May 18	627	3.5 ± 2.7	2.6 ± 2.3	1.5 ± 1.2	0.7 ± 0.9	0.4 ± 0.6	8.7	38.0
Jul 10	680	1.7 ± 0.9	2.0 ± 0.8	2.4 ± 1.2	0.9 ± 0.8	0.4 ± 0.4	7.4	249
Oct 05	767	1.0 ± 0.8	0.9 ± 0.8	0.7 ± 0.5	0.4 ± 0.3	0.2 ± 0.1	3.2	320

Table 6-8. Dissipation and leaching of hexazinone applied as Pronone 10G (4 kg ai/ha) in Grande Prairie soils (1986 - 1988)

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	101 ± 7	0	0	0	0	101	0.25
Sep 01	4	82 ± 22	0	0	0	0	82	0.51
Sep 05	8	57 ± 16	0.2 ± 0.7	0	0	0	57	11.7
Sep 10	13	53 ± 22	1.2 ± 0.8	0	0	0	54	12.2
Oct 04	37	27 ± 14	17 ± 9	7.4 ± 5.0	1.4 ± 1.3	0	53	106
Oct 28	61	15 ± 8	12 ± 3	11 ± 6	0.9 ± 0.5	0	39	110 (snowfall 95.3 cm)
1987								
Jun 10	286	14 ± 6	3.9 ± 0.9	2.2 ± 0.7	1.5 ± 2.1	0	22	44.3
Jul 15	321	12 ± 3	6.1 ± 3.3	1.4 ± 1.0	0.4 ± 0.2	0	20	129
Aug 28	365	4.2 ± 2.1	3.6 ± 2.1	1.2 ± 1.1	0.4 ± 0.4	0.3 ± 0.3	10	272
Oct 01	399	5.0 ± 2.5	3.6 ± 1.8	2.9 ± 1.3	0.8 ± 1.0	1.7 ± 2.0	14	285 (snowfall 119.4 cm)
1988								
May 18	627	2.8 ± 2.3	2.3 ± 2.7	2.6 ± 2.7	0.7 ± 0.8	0.4 ± 0.6	8.8	38.0
Jul 10	680	1.9 ± 1.7	1.3 ± 1.1	3.3 ± 1.9	0.8 ± 0.8	0.8 ± 1.1	8.1	249
Oct 05	767	1.0 ± 0.8	0.9 ± 1.3	1.7 ± 1.7	0.5 ± 0.2	0.7 ± 0.7	4.8	320

Table 6-9. Metabolite B detected in soils treated with 2 kg ai/ha Pronone 10G in Grande Prairie

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	0.4 ± 1.2	0	0	0	0	0.4	0.25
Sep 01	4	0	0	0	0	0	0	0.51
Sep 05	8	0.3 ± 1.0	0	0	0	0	0.3	11.7
Sep 10	13	10.3 ±12.2	0	0	0	0	10.3	12.2
Oct 04	37	0.7 ± 0.9	0	0	0	0	0.7	106
Oct 28	61	0.7 ± 1.7	0	0.6 ± 1.9	0.3 ± 0.3	0	1.6	110 (snowfall 95.3 cm)
1987								
Jun 10	286	0.2 ± 0.4	0	0.6 ± 1.7	1.0 ± 0.7	0	1.8	44.3
Jul 15	321	0.3 ± 0.6	0	0	1.1 ± 0.8	0	1.4	129
Aug 28	365	1.8 ± 2.2	0	0	0.3 ± 0.7	0.2 ± 0.4	2.3	272
Oct 01	399	1.2 ± 2.4	1.4 ± 2.8	0	0.1 ± 0.4	0.1 ± 0.2	2.8	285 (snowfall 119.4 cm)
1988								
May 18	627	0.2 ± 0.5	0	0	0	0.1 ± 0.2	0.3	38.0
Jul 10	680	0	0	0	0.2 ± 0.4	1.3 ± 1.0	1.5	249
Oct 05	767	0.4 ± 1.3	0	0	0.2 ± 0.3	0.3 ± 0.5	0.9	320

Table 6-10. Metabolite B detected in soils treated with 4 kg ai/ha Pronone 10G in Grande Prairie

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	0.5 ± 1.1	0	0	0	0	0.5	0.25
Sep 01	4	0.3 ± 0.9	0	0	0	0	0.3	0.51
Sep 05	8	0.6 ± 1.3	0	0	0	0	0.6	11.7
Sep 10	13	5.4 ± 4.3	0	0	0	0	5.4	12.2
Oct 04	37	0.2 ± 0.3	0	0	0	0	0.2	106
Oct 28	61	0.1 ± 0.2	0	0.3 ± 0.9	0.3 ± 0.4	0	0.7	110 (snowfall 95.3 cm)
1987								
Jun 10	286	0.1 ± 0.3	0	0	0.6 ± 1.0	0	0.7	44.3
Jul 15	321	0.4 ± 0.8	0	0.3 ± 0.8	0.4 ± 0.4	0	1.1	129
Aug 28	365	0.3 ± 0.5	0	0	0	0.3 ± 0.4	0.6	272
Oct 01	399	0.3 ± 0.6	1.0 ± 2.1	0	0	0.1 ± 0.3	1.4	285 (snowfall 119.4 cm)
1988								
May 18	627	0	0	0	0	0.2 ± 0.3	0.2	38.0
Jul 10	680	0	0	0.4 ± 1.2	0	0.3 ± 0.2	0.7	249
Oct 05	767	0.8 ± 1.7	0	0.3 ± 0.8	0.4 ± 0.4	0.5 ± 0.4	2.0	320

1985) was observed in similar pattern as for metabolite B, but at a lower scale in both 2 and 4 kg ai/ha treatments (Tables 6-11 and 6-12). The highest level of metabolite A was also found 13 days after treatment and showed 8.7 and 4.1% relative to 2 and 4 kg/ha of hexazinone applied, respectively. Results of this study suggested that degradation of hexazinone to metabolite B through demethylation was greater than to metabolite A, that these degradation processes were continuous and noncumulative in soils as deep as 40 cm, and at a low level of no detrimental effect to the environment.

The regression equations for the dissipation of hexazinone over time were calculated for all individual soil layers and their combined total depth (0-40 cm) based on means of each treatment and depth at different time periods (Table 6-13). The dissipation patterns in the top layer (0-10 cm) had a close resemblance to each other and the combined totals in both 2 and 4 kg/ha treatments. Similarly, in both treatments, the next three deeper layers, 10-20, 20-30, and 30-35 cm, showed similar types of dissipation curve but on a descending order of dissipation rate. The correlation coefficients of residue dissipation with time in these soil layers were 0.90-0.99 and 0.86-0.98, respectively, in 2 and 4 kg ai/ha treatments. In the deepest layer, 35-40 cm, due to the small amounts of residues recovered and the slow rate of penetration, the pattern of dissipation was different from all shallower layers and was different between 2 and 4 kg ai/ha treatments. Their correlation coefficients were also lower. Times required for residues to dissipate to 50% of amounts applied (DT_{50}) were 12 and 27 days, respectively, for 0-10 cm and the combined total (0-40 cm) layers in 2 kg ai/ha treatment; and 13 and 29 days, respectively, in 4 kg ai/ha treatment.

6.5 HORIZONTAL AND VERTICAL VARIATION OF HEXAZINONE IN SOILS[27]

6.5.1 Background

Aerial application of PRONONE 10G granules by using an Isolair-helicopter system did not produce uniform distribution of granules over a small surface area (Section 5.3). Variations of granule weight collected by 10 trays of 1100 cm^2 each for every 5 m along two parallel collection transects, perpendicular to the helicopter flight path, were ranged between 21% and 86% CV when 48 replications were accounted for (Feng 1989). These large variations would have direct impact on vegetation survey and residue sampling, if similar small areas were used. However, variations of the mean values of the 10-tray mean from three replicated plots reduced to a range of 8-34% CV for these aerial applications. Horizontal and vertical distribution of hexazinone residues in soils in these vegetation plots were investigated one and two years after the aerial application of PRONONE 10G. The variation of hexazinone residues in soil was estimated by sampling all herbicide-treated plots down to 30 and 220 cm depths after 1 and 2 years, respectively.

6.5.2 Materials and Methods

6.5.2.1 Site description and herbicide application

The study site located in the Grande Prairie area was clearcut in 1983, treated with hexazinone (PRONONE 10G) on August 28, 1986, and planted with white spruce and lodgepole pine in spring 1987 (Section 4.2). Weed competition was mainly from grasses, shrubs, and aspen of average height of 1 m in 1986 and 2 m in 1988 (Fig. 4-7A). The soil texture was silty loam. Three soil horizons, LH,

---

[27]Feng, Sidhu, and Feng (1989a).

Table 6-11. Metabolite A detected in soils treated with 2 kg ai/ha Pronone 10G in Grande Prairie

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	2.5 ± 4.7	0	0	0	0	2.5	0.25
Sep 01	4	0	0	0	0	0	0	0.51
Sep 05	8	1.0 ± 2.9	0	0	0	0	1.0	11.7
Sep 10	13	8.7 ± 5.5	0	0	0	0	8.7	12.2
Oct 04	37	1.6 ± 3.0	0	0	0	0	1.6	106
Oct 28	61	0.5 ± 1.6	0	0	0	0	0.5	110 (snowfall 95.3 cm)
1987								
Jun 10	286	0.4 ± 0.7	0	0	0	0	0.4	44.3
Jul 15	321	0	0	1.0 ± 3.0	0	0	1.0	129
Aug 28	365	0.1 ± 0.3	0	0	0	0	0.1	272
Oct 01	399	0.7 ± 1.8	0	0	0	0	2.5	285 (snowfall 119.4 cm)
1988								
May 18	627	0	0	0	0	0	0	38.0
Jul 10	680	0	0	0	0	0	0	249
Oct 05	767	2.4 ± 5.0	0	1.9 ± 2.9	1.2 ± 1.9	0.5 ± 1.0	6.0	320

Table 6-12. Metabolite A detected in soils treated with 4 kg ai/ha Pronone 10G in Grande Prairie

Post application		Mean hexazinone residues (%) ± S.D.						Annual cumulative rainfall (mm)
		Soil depth (cm)						
Date	Days	0 - 10	10 - 20	20 - 30	30 - 35	35 - 40	Total	
1986								
Aug 30	2	0.2 ± 0.7	0	0	0	0	0.2	0.25
Sep 01	4	0.7 ± 2.0	0	0	0	0	0.7	0.51
Sep 05	8	0.4 ± 1.0	0	0	0	0	0.4	11.7
Sep 10	13	4.1 ± 4.2	0	0	0	0	4.1	12.2
Oct 04	37	0.5 ± 0.8	0.4 ± 0.7	0	0	0	0.9	106
Oct 28	61	0.2 ± 0.5	0.3 ± 1.0	0.7 ± 1.4	0	0	1.2	110
1987								(snowfall 95.3 cm)
Jun 10	286	0.2 ± 0.6	0	0	0	0	0.2	44.3
Jul 15	321	0	0.5 ± 0.9	0	0	0	0.5	129
Aug 28	365	0.1 ± 0.3	0	0	0	0	0.1	272
Oct 01	399	0	0	0	0	0	0	285
1988								(snowfall 119.4 cm)
May 18	627	0	0	0	0	0	0	38.0
Jul 10	680	0	0	0	0	0	0	249
Oct 05	767	2.8 ± 5.3	0.4 ± 1.2	1.3 ± 2.1	0.9 ± 1.6	0.6 ± 0.9	6.0	320

Table 6-13. Equations illustrating leaching and dissipation of hexazinone in soil by time at different depths at two rates of Pronone 10G treatments

Rate applied (kg/ha)	Soil depth (cm)	Equation[a]	R	N
2	0 - 10	log (Y + 0.01) = 2.03 - 0.290 log X - 0.00136 X	0.99	13
	10 - 20	log (Y + 0.01) = -2.51 + 2.01 log X - 0.00460 X	0.90	13
	20 - 30	log (Y + 0.01) = -3.05 + 1.84 log X - 0.00308 X	0.90	13
	30 - 35	log (Y + 0.01) = -2.86 + 1.45 log X - 0.00222 X	0.92	13
	35 - 40	log (Y + 0.01) = -2.10 + 0.070 log X + 0.00221 X	0.78	13
	Total 0 - 40	log (Y + 0.01) = 1.97 - 0.168 log X - 0.00105 X	0.98	13
4	0 - 10	log (Y + 0.01) = 2.06 - 0.313 log X - 0.00131 X	0.98	13
	10 - 20	log (Y + 0.01) = -2.53 + 2.02 log X - 0.00471 X	0.92	13
	20 - 30	log (Y + 0.01) = -2.96 + 1.78 log X - 0.00273 X	0.86	13
	30 - 35	log (Y + 0.01) = -2.77 + 1.37 log X - 0.00201 X	0.89	13
	35 - 40	log (Y + 0.01) = -1.97 - 0.092 log X + 0.00308 X	0.85	13
	Total 0 - 40	log (Y + 0.01) = 2.02 - 0.203 log X - 0.00088 X	0.98	13

[a]Y = percent hexazinone residues of amounts applied; X = time (days) post-application.

Ah, and Ae, can be found within 10-20 cm depth from the surface. PRONONE 10G (10% hexazinone, w/w; surface-coated granule) was applied to triplicated 80 × 200 m plots (Fig. 4-5) at 2 and 4 kg ai/ha rates by a helicopter equipped with an Isolair bucket spreader (Fig. 4-4) on 28 August 1986 under a no-wind condition.

6.5.2.2 Soil sampling to determine the general distribution of hexazinone in the treatment plots

The aerially applied granular formulation would produce spot coverage of the active ingredient on the ground. Representative soil sampling for the level of herbicide residues in the vegetation plots could not be achieved initially. Soil samples were taken one year after application in a grid pattern from the central 30 × 100 m area of all six treatment plots. Two rows of five soil collection spots were evenly spaced at a 20-m distance. A 35- to 40-cm deep soil column was removed from each spot with a shovel. The clean uncontaminated center of the soil column was separated into three subsamples at 0-10, 10-20, and 20-30 cm soil depths. Five soil samples from each treatment block were analyzed separately to determine the residue concentrations of hexazinone and metabolites A and B and the variation of residues over the entire treated area.

6.5.2.3 Deep-pit soil sampling to determine the degree of vertical leaching of hexazinone

Due to the positive identification of hexazinone residues at 30 cm soil depth one year after application, deep-pit soil sampling was conducted two years after application to assess the maximum penetration of hexazinone residues. One soil pit in each treatment plot was dug to a 2.5 m depth by using a backhoe. From each soil pit, soil disks of 10 cm thickness were taken in triplicate (three vertical sampling lines with 1 m spacing) from the surface to 220 cm deep at 20 cm intervals. A total of 8 depths were sampled: 0-10, 30-40, 60-70, 90-100, 120-130, 150-160, 180-190, and 210-220 cm from the surface of the forest floor.

6.5.2.4 Sample preparation and residue analysis

Soil samples were air-dried, homogenized, and sifted by the method of Feng and Klassen (1986). Hexazinone residues were extracted and cleaned by using a new method developed in this project (Section 5.7). Residues and metabolites of hexazinone were analyzed and quantified by capillary gas chromatography (Feng 1987; Feng, Feng, and Sidhu 1989; Feng, Sidhu, Feng, and Servant 1989). Residue concentrations in soils were reported either on a weight basis (ppmw) or were converted to a soil area basis (kg/ha) by using soil bulk densities of each horizon (Feng and Klassen 1986).

6.5.3 Results and Discussion

6.5.3.1 Persistence and uniformity of hexazinone one year after treatment

Mean residue concentrations of every five replicates per treatment block, the mean of means of three blocks per rate, and their standard errors are reported in Tables 6-14 and 6-15 for 2 and 4 kg ai/ha treatments, respectively. Hexazinone concentrations were relatively homogenous at about 0.5 ppmw level at 0-10 cm depth in all treatment blocks of both application rates (2 and 4 kg ai/ha) and were about 0.2 and 0.05 ppmw at 10-20 and 20-30 cm depths.

Variations among replicated samples were generally greater than the mean values (Tables 6-14 and 6-15). However, one year after application, these residue levels represented only 5 and 10% of hexazinone originally applied within 0-10 and 0-30 cm depths (Section 6.4). Greater relative variations were expected when residue concentrations reduced to such low levels under field conditions. Reducing gradients of residues were also observed from the surface of the forest floor to the deeper soils. Hexazinone residues in soils were mainly concentrated at the rooting zone between 0 and 20 cm in depth one year after application. Some residual effect for weed control could be expected in the second and perhaps the third growing season.

Concentrations of metabolite B were found at about one-third that of hexazinone; metabolite A was about 10-20% at 0-10 cm depth and zero between 10-30 cm. Results indicated a continual noncumulative degradation of hexazinone down to 30 cm of soil depth and more active demethylation than hydroxylation. Since metabolite B was only 1% as phytotoxic as hexazinone and metabolite A was nonphytotoxic (Sung et al. 1985), these low concentrations were not expected to pose any detrimental effect to the environment.

6.5.3.2 Deep soil sampling for hexazinone leaching

In the 4 kg/ha treatment, hexazinone residues were detected in the top 10-cm soils and averaged about 0.8% of the original amount applied. Trace amounts (or less than 0.75% of the originally applied hexazinone) were found between 30 and 40 cm soil depth (Table 6-16) and were similar to the previous finding that 0.7-1.2% of originally applied hexazinone was found between 30 and 40 cm soil depth one year after application (Section 6.4). No residues were detected at any other depths.

In the 2 kg/ha treatment, only one sample showed trace amounts of residues in the 0-10 cm layer (Table 6-17). However, detectable amounts of hexazinone residues were found in all samples at the 30-40 cm depth. Trace amounts of hexazinone were also found in two samples at the 60-70 cm soil depth and one sample each at 90-100 and 120-130 cm. No detectable residues were found below 150 cm (Table 6-17). Feng, Sidhu, Feng, and Servant (1989) reported the presence of very small amounts of hexazinone residues in the soil leachate at 80 cm soil depth in a nearby location in the same treatment block. Leaching through channels formed by groups of dried, dead roots of mature trees previously logged was most likely the cause of the downward movement of hexazinone in this area. This was further evidenced by the fact that no detectable residues were found deeper than 40 cm in the 4 kg ai/ha treatment area where no root channels were found at the sampling sites.

6.6 HEXAZINONE RUNOFF IN EPHEMERAL AND PERMANENT STREAMS[28]

Hexazinone is water soluble (3.3%, w/w) (WSSA 1983) and has the potential for lateral movement with surface runoff. Barring and Torstensson (1983) found that hexazinone moved with water at least 2 m down a 12-22 degree slope. In another study, the lateral movement was not detected 20 m downslope on a 5-10% gradient (Feng 1987). In a stream directly treated with hexazinone pellets, waterborne hexazinone decreased to less than half of the initial concentration within 1 hour after application at a point adjacent to the treated area (Miller and Bace 1980). Neary, Bush, and Douglass (1983) and Neary, Bush, and Grant (1986) reported in a study monitoring stormflow and baseflow through 26 storm events over a 13-month period that an estimated 0.53% of the hexazinone applied was lost through runoff; in another study, Neary (1983) found no residues in groundwater and springflow beyond 20 m from the treated area.

---

[28]Feng, J.C. (Unpublished data.)

Table 6-14. Mean (n=5 per block) residue concentrations of hexazinone and metabolites, A and B, in soils of triplicated blocks one year after treated with PRONONE 10G at 2 kg ai/ha

Chemical name	Soil depth (cm)	Mean residues in soil (ppmw, μg/g)			
		Block 1	Block 2	Block 3	Mean (n=3)
Hexazinone	0-10	0.57 ± 1.08	0.57 ± 0.62	0.24 ± 0.22	0.46 ± 0.19
	10-20	0.30 ± 0.25	0.46 ± 0.39	0.10 ± 0.06	0.29 ± 0.18
	20-30	0.03 ± 0.02	0.05 ± 0.06	0.02 ± 0.01	0.03 ± 0.02
Metabolite-B	0-10	0.19 ± 0.28	0.17 ± 0.18	0.15 ± 0.21	0.17 ± 0.02
	10-20	0	0.12 ± 0.17	0.09 ± 0.13	0.07 ± 0.06
	20-30	0	0.02 ± 0.03	0	0.01 ± 0.01
Metabolite-A	0-10	0.05 ± 0.07	0.04 ± 0.05	0.17 ± 0.24	0.09 ± 0.07
	10-20	0	0	0	0
	20-30	0	0	0	0

Table 6-15. Mean (n=5 per block) residue concentrations of hexazinone and metabolites, A and B, in soils of triplicated blocks one year after treated with PRONONE 10G at 4 kg ai/ha

Chemical name	Soil depth (cm)	Mean residues in soil (ppmw, μg/g)			
		Block 1	Block 2	Block 3	Mean (n=3)
Hexazinone	0-10	0.61 ± 0.71	0.78 ± 1.08	0.61 ± 0.90	0.67 ± 0.10
	10-20	0.14 ± 0.11	0.09 ± 0.10	0.28 ± 0.18	0.17 ± 0.10
	20-30	0.13 ± 0.16	0.06 ± 0.05	0.04 ± 0.05	0.08 ± 0.05
Metabolite-B	0-10	0.33 ± 0.36	0.18 ± 0.17	0.18 ± 0.33	0.23 ± 0.09
	10-20	0.03 ± 0.03	0.12 ± 0.26	0.13 ± 0.12	0.09 ± 0.06
	20-30	0.01 ± 0.01	0.02 ± 0.03	0	0.01 ± 0.01
Metabolite-A	0-10	0.09 ± 0.12	0.01 ± 0.02	0.06 ± 0.13	0.05 ± 0.04
	10-20	0	0.04 ± 0.09	0.24 ± 0.23	0.09 ± 0.13
	20-30	0	0.01 ± 0.01	0	0

Table 6-16. Deep soil sampling for hexazinone residues two years after treatment with PRONONE 10G at 4 kg ai/ha rate

Soil depth (cm)	Hexazinone residues (kg/ha)			
	Line 1	Line 2	Line 3	Mean
0 - 10	0.031	0.034	0.041	0.035 ± 0.005
30 - 40	TRACE	TRACE	0.044	0.015 ± 0.025
60 - 70	ND	ND	ND	ND
90 - 100	ND	ND	ND	ND
120 - 130	ND	ND	ND	ND
150 - 160	ND	ND	ND	ND
180 - 190	ND	ND	ND	ND
210 - 220	ND	ND	ND	ND

Note: TRACE = 0.001-0.01 kg/ha; ND = Non-detectable, < 0.001 kg/ha.

Table 6-17. Deep soil sampling for hexazinone residues two years after treatment with PRONONE 10G at 2 kg ai/ha rate

Soil depth (cm)	Hexazinone residues (kg/ha)			
	Line 1	Line 2	Line 3	Mean
0 - 10	TRACE	ND	ND	TRACE
30 - 40	0.107	0.059	0.011	0.059 ± 0.048
60 - 70	TRACE	TRACE	ND	TRACE
90 - 100	ND	TRACE	ND	TRACE
120 - 130	TRACE	ND	ND	TRACE
150 - 160	ND	ND	ND	ND
180 - 190	ND	ND	ND	ND
210 - 220	ND	ND	ND	ND

Note: TRACE = 0.001-0.01 kg/ha; ND = Non-detectable, < 0.001 kg/ha.

Although there is no permanent water body adjacent to the Grande Prairie project's Method II experimental area, there is a very small ephemeral channel around the northeastern and southeastern sides of lower half of Block 2 and the entire Block 1. Most parts of this ephemeral channel were about 10-30 cm wide with pools of no more than 30-50 cm diameter and one larger shallow pool of about 2-3 m wide. The channel then flows north through the western side of both Blocks 1 and 2 and drains into Campbell River, a permanent stream about 1 km west. With the agreement and assistance of the staff of the Chemical Control Branch, Alberta Environment, these water bodies were monitored by collecting surface water and bottom sediment samples from seven points: one near the southeastern corner of Block 1 at the large shallow pool (designated as Site No. 1) and six along the Campbell River (designated as Sites No. 2-7 in downstream direction) to a total distance of about 3 km. Duplicate samples were collected at different time periods, mostly coinciding with rain events during 1986 and 1987.

Hexazinone concentrations in surface water and bottom sediments were determined by extraction, cleanup, and gas chromatography, and are presented in Table 6-18. Results indicated that no hexazinone residues were carried by the surface runoff to enter the Campbell River. However, there were dilute amounts of hexazinone residues (up to 5 ppb) found in the surface water and up to 0.24 ppm (μg/g dry weight) in sediments in the shallow pool (Site No. 1) about 40 m from the southeastern corner of plot 1, Block 1. Hexazinone contamination at Site No. 1 found in 1986 and 1987 was probably due to the foot traffic of various groups of research staff initially working in that area and carrying residues on boots through the pool to the cutline. Hexazinone residue level dissipated to the nondetectable level by 1988 (Table 6-19).

Sample collections were modified in 1988 to isolate the source of contamination near the treatment blocks and plots (Site No. 1). The six collection points (Sites No. 2-7) at the Campbell River were discontinued and were replaced by eight additional collection points: four upstream from Site No. 1, designated as Sites A, B, C, and D and four downstream designated as Sites E, F, G, and H. All upstream collection points were 100-150 m apart to cover the entire northeastern side between the divide from the lower part of Block 2 and the lowest part of Block 1 at Site No. 1. All downstream collection points were about 50-80 m apart to cover the south eastern side of Block 1, the lowest point of the experimental area.

Results of the 1988 monitoring showed very low concentration (at 1 ppb level) of hexazinone in all sites upstream (A, B, C, and D) but no residues in Site No. 1 and its downstream sites (E, F, G, and H) (Table 6-19). Sites A to D were located in the northeastern area outside the experimental Blocks 1 and 2, which was contaminated by aerial application involving early release of Pronone 10G (prior to reaching the boundary) to ensure the full coverage of herbicide to the experimental plots. The size of the contaminated area was not certain, and this area was drained to the ephemeral channel about 10-30 m downslope on the northeastern side of the contaminated areas.

The overall residue levels of hexazinone found in surface water and sediment near the treatment areas were very small and would have no impact on the environment. The maximum level of hexazinone residues were compared with the LD_{50} and LC_{50} levels for various wildlife and fish species, and their ratios are calculated and reported in Table 6-20.

Table 6-18. Hexazinone concentration in surface water and sediments outside the area treated with Pronone 10G on 28-08-1986 in Grande Prairie

Days postspray	Date sampling	Water (μg/L; ppb)		Sediment (μg/g dry wt.)	
		Site No. 1	Site No. 2	Site No. 1	Site No. 2
12	09-09-86	-	< 1	< 0.03	< 0.03
47	14-10-86	< 1	< 1	< 0.03	< 0.03
236	21-04-87	4.2	< 1	< 0.03	< 0.03
264	19-05-87	4.2	< 1	0.24	< 0.03
271	26-05-87	1.1	< 1	0.03	< 0.03
277	01-06-87	1.0	< 1	TRACE	< 0.03
340	03-08-87	-	-	TRACE	< 0.03
343	06-08-87	1.5	< 1	TRACE	< 0.03
344	07-08-87	5.0	< 1	-	-

Note: Detection limits were 1 ppb and 0.03 ppm for water and sediment, respectively.

Table 6-19. Hexazinone concentrations in surface water of new sampling sites established in 1988, outside the area treated with Pronone 10G on 28-08-1986 at the Grande Prairie Method II experimental area

Days postspray	Date sampling	Hexazinone residues in water (μg/L; ppb)				
		Site A	Site B	Site C	Site D	Site No. 1, E, F, G. H
651	10-06-88	1.07	1.02	1.48	1.07	< 1
689	18-07-88	1.63	1.31	1.13	1.06	< 1

Note: Detection limit = 1 ppb.

Table 6-20. Ratio of hexazinone toxicity (LC_{50}) and the maximum detected residues in surface water (Site No. 1)

Wildlife/fish	LC_{50} (ppm)	Ratio (LC_{50}: Site No. 1 residues)
Mallard duckling	5000 (8 days)	1,000,000 : 1
Bobwhite quail	5000 (8 days)	1,000,000 : 1
Trout	320-420 (96 h)	65,000 - 85,000 : 1
Bluegill sunfish	370-420 (96 h)	70,000 - 85,000 : 1
Fathead minnow	274 (96 h)	55,000 : 1

6.7 UPTAKE AND DISSIPATION OF HEXAZINONE IN VEGETATION[29]

6.7.1 Background

After the hexazinone is absorbed by roots and translocated to the foliage, its levels of accumulation and duration of persistence in twigs, foliage, fruits, and leaf litter become important to the wildlife and humans who may use the sprayed areas for shelter, food, or just a visit. Such information was lacking for the boreal mixedwood before the present study was undertaken. The mode of action of hexazinone in plants is summarized in Section 4.3.1.1. Baron and Monaco (1986) reported that for blueberry and hollow goldenrod 10% of the herbicide applied was absorbed by roots, and less than 10% of the root-absorbed herbicide was translocated to the stem and leaves where it accumulates and causes leaf damage. They studied the distribution of hexazinone in plants grown in nutrient solution under controlled conditions. Similar studies on woody species have been carried out by McNeil, Stritzke, and Basler (1984). Lavy et al. (1989) reported maximum average foliar hexazinone concentrations of 0.96 ± 0.82 ppm in August (on-tree leaves) and 0.09 ± 0.24 in November (on-ground leaves). The foliage samples were a mixture of *Quercus rubra, Acer rubrum, Fagus grandiflora*, and *Sassafras albidum*. They reported mean hexazinone concentration in green leaves to vary from 0.5 to 1.0 ppm. In their study, the hexazinone concentrate was applied by spot-gun at a rate of 1.36 kg ai/ha. No other field studies related to hexazinone residues in plant species are available in the literature to date.

6.7.2 Methods

The field sampling of the foliage and twigs of dominant species was designed to establish

1) a reliable estimate of the hexazinone residue in the overwintering twigs of dominant woody species that were identified as candidates for winter browse for wildlife;

2) accumulation trends in hexazinone and its metabolites in selected leading woody, herbaceous, and grass species, and in fresh leaf litter in the treated plots; and

---

[29]Sidhu, Feng, and Feng (1989).

3) a broad perspective of levels of residues in a large number of species representative of the study area after 2-3 years of PRONONE 10G application.

The foliage and twig samples were collected in bulk from 20-cm top sections of branches from 20 stems (or more to make up >50 g of sample materials) in case of woody species, 20 whole plants of herbaceous species, or 20 grab samples of grasses and leaf litter. The 20 sampling points were distributed at regular intervals along two transects traversing the two corridors in each treatment plot between the central and two side rows of permanent quadrats (Fig. 4-5).

The samples were collected at about 30-day intervals for *Populus tremuloides, Calamagrostis canadensis, Aster conspicuus*, and fresh litter. Other species were sampled at 60-day intervals in 1987 and once a year 1988 and 1989 (Table 6-22). The samples were collected in plastic bags, stored in an icebox after collection, and transported to a freezer (-5°C) at the end of the day. The samples were kept frozen until analyzed.

The moisture content of the samples was determined by oven-drying 10-g aliquots of fresh-frozen samples at 105°C for 48 hours at the time of residue analysis. Residues of hexazinone and its major metabolites were determined by using a newly developed analytical method involving methanol extraction, microcolumn cleanup, and capillary gas chromatography (Section 5.7.3). Residue concentrations were converted into μg/g (ppm) on a dry weight basis.

The herbicide was applied in August 1986. Throughout the text, first and second growing seasons refer to the 1987 and 1988 growing seasons.

6.7.3 Results and Implications

No hexazinone residues were detected in samples from control plots. Hexazinone concentrations found in 1986 (twigs of aspen, Saskatoonberry, and willow) from herbicide-treated plots are summarized in Table 6-21. Foliage of these species, after herbicide application on 28 August to 31 October 1986, did not show any herbicide damage symptoms. However, presence of hexazinone residues in the overwintering twigs (Table 6-21) of 1986 growth of *Calamagrostis* (Table 6-22) and on-plant leaves of aspen indicated the absorption of some hexazinone by these species after application of PRONONE 10G in August 1986. Maximum consumption of hexazinone by animals by way of aspen twigs, 1986 aspen leaves, and 1988 *Calamagrostis* growth is calculated to be 0.04 mg (40 μg), 0.26 mg (260 μg), and 2.30 mg (2300 μg) per kg (1000g) of dry mass consumed. The moisture content (percent wet weight basis) of the twigs in fall 1986 varied from 43 to 49%.

The 1987 and 1988 levels of hexazinone residues are summarized in Table 6-22. The residue levels were different among species due to the differences in their phenology, their physiological response to the herbicide, and variations in distribution of the granular herbicide (Section 5.1) in relation to the distribution of species. In spite of these variation the following general conclusions can be drawn:

1) The hexazinone concentrations in foliage and twigs were maximal during May to July of the first growing season (1987) following the 1986 fall application of PRONONE 10G.

2) *Calamagrostis* accumulated the most residues followed by *Salix, Aster, Rosa, Amelanchier, Lonicera*, and *Epilobium. Calamagrostis canadensis* was the most sensitive species and can be used as a good biomonitor over long monitoring periods.

3) The concentration of hexazinone in twigs was 0.56, 0.59, and 7.7% of that in the leaves of *Salix*, *Populus*, and *Lonicera* respectively. In species of which stems died off each winter, the concentration of hexazinone in twigs as percentages of that in foliage increased. For example, in *Epilobium* and *Rosa* the percentages were 20.0 and 16.7 respectively. Depending on the species, the wildlife is expected to consume significantly less hexazinone residue through the winter browse than through the summer foliage.

4) The foliage and fruit of *Vaccinium myrtilloides* had accumulated very low levels of hexazinone.

5) The freshly fallen leaves had significantly higher residue levels than the damaged leaves still attached to the stem. The higher levels of hexazinone in leaf litter will be significant from the point of view of impact on the fauna feeding on the litter.

6) Variations among the three blocks (replicates) were significant as indicated in the standard deviations. These deviations were much greater when the detected residues were low. Variations between times of collections within species was also caused by relative contribution of damaged and undamaged foliage because of intermittent new growth between periods of absorption, damage, and defoliation.

7) In general, residue levels in all species declined toward the end of the first growing season (1987) and practically no residues were detected by the end of the second growing season (1988) except in *Aster, Calamagrostis, Amelanchier*, and *Lonicera* among the monitored species.

The first growing season after the herbicide application is critical for the hexazinone concentrations in vegetation as these tend to be practically absent or at low levels, if not by the end of the first growing season, definitely by the second. The sensitive species like *Calamagrostis* and *Aster*, which tend to absorb and accumulate the most, were the only species that contained any detectable amounts of hexazinone in their foliage at the end of the second growing season following the herbicide application. The highest residues were detected during May and June of the first growing season following the fall application, which corresponded to or preceded the maximum foliar damage to the vegetation (Table 4-1).

The presence of both metabolite B, a demethylation product (Table 6-23), and metabolite A, a hydroxylation product of hexazinone (Table 6-24), were detected at similar to or lower levels than that of hexazinone in foliage of all species except Saskatoonberry (Table 6-22). Strong demethylation of hexazinone occurred in Saskatoonberry at the end of the first growing season (September 1987) and during the second growing season (August 1988). The most active dehydroxylation of hexazinone was observed in showy aster relatively early during the first growing season in May 1987. Unlike other species, the disappearance of both metabolites A and B in trembling aspen started 3 to 5 months earlier than in other species. In fresh litter, concentration of metabolite B was about 10% that of hexazinone. A relatively much lower level of metabolite A was present throughout the monitoring period, indicating a stronger process of demethylation by microorganism than of hydroxylation. Sung et al. (1985) reported that the phytotoxicity of metabolite B was 1% that of hexazinone and that metabolite A was not phytotoxic. The concentration levels of either metabolite A or B found in this study would not have any herbicidal or toxic effects and would pose no threat to the environment.

Table 6-21. *Average (±S) concentration of hexazinone residues in twigs of three browse species. The hexazinone was applied as Pronone 10G on 28 August 1986

Sampling date Species/plant date	Hexazinone residue		Moisture content	
	2 kg ai/ha	4 kg ai/ha	2 kg ai/ha	4 kg ai/ha
31 October 1986:	----------(μg/g, dry wt.)----------		----------(%, wet wt.)----------	
Amelanchier alnifolia - twigs	0.02 ± 0.01	0.02 ± 0.03	43.2 ± 3.50	43.1 ± 0.00
Populus tremuloides - twigs	0.01 ± 0.01	0.02 ± 0.02	48.0 ± 3.0	47.8 ± 2.5
Salix sp. - twigs	0.02 ± 0.02	0.05	48.7 ± 2.0	48.8 ± 2.4

*Average (n = 3), mean of 3 Bulk samples (Each bulk sample of 20 twigs (20 cm of top 1986 growth) from each treatment plot), 64 days after herbicide application.

Table 6-22. Hexazinone residues (μg/g, dry wt.) in selected species during 1987-88 in samples from high herbicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots

SPECIES	1987 SAMPLING										1988 SAMPLING		MAXIMUM	
	26 MAY		23 JUNE		22 JULY		23 AUGUST		2 SEPT		3 AUGUST			
	HH	LH	HH	LH	HH	LL	HH	LH	HH	LL	HH	LH	HH	LH
	(μg/g, dry wt.)													
Populus tremuloides														
Foliage (bulk)	1.03 ±0.84	0.31 ±0.28	1.58 ±0.26	0.71 ±0.31	1.19 ±0.01	0.51 ±0.38	0.14 ±0.25	0.0 -	0.04 ±0.06	0.0	0.00	0.00	1.87	1.01
'87 100% damaged on-plant foliage	1.27	-	3.35											
"86 on-plant foi	0.26													
twigs	0.00	0.00	0.00	0.01 ±0.01	0.01 ±0.02	0.0	0.0	0.0	0.0	0.0	-	-	0.03	0.02
Fresh litter	2.56 ±1.87	3.64 ±3.67	4.09 ±2.17	1.24 ±0.66	0.85 ±0.46	0.54 ±0.28	0.50 ±0.31	0.55 ±0.67	0.24 ±0.07	0.13 ±0.03	- -	- -	6.45	7.83
Calamagrostis canadensis														
'86 Growth	1.73 ±0.54	1.16 ±0.23	-	-	-	-	-	-	-	-				
"87 Growth	7.32 ±3.49	4.92 ±2.31	2.22 ±2.60	1.96 ±0.66	0.74 ±0.35	0.43 ±0.25	ns	0.26 ±0.16	ns	0.35 ±0.18	0.73	0.13	11.18	7.54
Aster conspicuous														
Foliage	2.86 ±0.97	2.48 ±1.71	1.99 ±1.23	0.82 ±0.49	0.77 ±0.99	2.56 ±0.83	0.17 ±0.30	0.24 ±0.08	0.81 ±0.22	0.53 ±0.10	0.00	0.03	3.43	4.43
Twigs	-	-	0.37 ±0.12	0.07 ±0.02	0.19 ±0.07	0.13 ±0.10	0.19 ±0.09	0.06 ±0.08	0.15 ±0.06	0.00 -	-	-	0.44	0.25
A. ciliolatus											0.75	0.00		
Salix spp														
Foliage	3.59	0.98			0.43 ±0.09	0.23 ±0.12	-	-	0.04 ±0.06	0.14 ±0.05	0.00	0.00	3.59	0.98
Twigs	0.02	0.00			0.00	0.00			0.06 ±0.07	0.00				
Amelanchier alnifolia														
Foliage	0.71 ±0.28	0.59	-	-	1.68	1.69 ±1.24			1.00	0.95 ±0.13	0.07	0.00	2.38	2.42
Twigs	0.02 ±0.00	0.00	-	-	0.03 ±0.03	0.00			0.03 ±0.05	0.03 ±0.03	-	-	0.08	0.05

Table 6-22 (Contd.)

Rosa acicularis														
Foliage	1.50	0.79	-	-	1.13 ±1.06	0.12 ±0.07			0.81 ±0.16	0.36 ±0.36	0.00	0.00	1.50	0.70
Twigs	-	-	-	-	0.14 ±0.11	0.03 ±0.06	-	-	0.06 ±0.08	0.05 ±0.02	-	-	0.30	0.10
Epilobium angustifolium														
Foliage	0.20	0.18	-	-	0.33 ±0.23	0.05 ±0.09	-	-	0.02 ±0.03	0.00	0.00	0.00	0.55	0.18
Twigs	-	-	-	-	0.06 ±0.07	0.00			0.02 ±0.03	0.02 ±0.03	-	-	0.13	0.05
Lonicera involucrata														
Foliage	0.51	-									0.03	0.00		
Twigs	0.04	-												
L. dioica														
Foliage											0.00	0.00		
Viburnum edule														
Foliage											0.00	0.00		
Corylus cornuta														
Foliage											0.00	0.00		
Shepherdia canadensis														
Foliage											0.00	0.00		
Spiraea betulifolia														
Foliage											0.00	0.00		
Cornus canadensis														
Foliage											0.00	0.00		
C. stolonifera														
Foliage											0.00	0.00		
Aralia nudicaulis														
Foliage											0.00	0.00		
Vicia americana														
Foliage											0.00	-		
Galium boreale														
Foliage											0.03	0.00		
Castilleja miniata														
Foliage											0.00	0.00		

HH = 4 kg hexazinone/ha treatment, LH = 2 kg hexazinone/ha treatment, Hexazinone was applied as PRONONE 10 G.
*Values followed by SD are averages of 3 replicates.

Table 6-23. Metabolite-B (μg/g, dry wt.) in selected species during 1987-88 in samples from high hebcicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots

SPECIES	1987 SAMPLING										1988 SAMPLING		MAXIMUM	
	26 MAY		23 JUNE		22 JULY		23 AUGUST		2 SEPT		3 AUGUST			
	HH	LH	HH	LH	HH	LL	HH	LH	HH	LL	HH	LH	HH	LH
	(μg/g, dry wt.)													
Populus tremuloides														
Foliage (bulk)	0.07 ±0.12	0.0	0.28 ±0.11	0.14 ±0.13	0.26 ±0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.37	0.26
'87 100% damaged on-plant foliage	0.58	-	0.63										0.63	-
"86 on-plant fol	0.0													
twigs	0.0	0.0	0.10 ±0.11	0.26 ±0.25	0.08 ±0.14	0.06 ±0.11	0.03 ±0.05	0.05 ±0.05	0.04 ±0.07	O.03 ±0.03	-	-	0.25	0.50
Fresh litter	0.21 ±0.04	0.18 ±0.15	0.51 ±0.23	0.17 ±0.09	0.29 ±0.01	0.20 ±0.06	0.13 ±0.02	0.11 ±0.10	0.0	0.0	- -	- -	0.77	0.36
Calamagrostis canadensis														
'86 Growth	0.73 ±0.21	0.46 ±0.14	-	-	-	-	-	-	-	-			0.86	0.61
"87 Growth	2.54 ±0.65	2.50 ±1.95	0.74 ±0.55	1.12 ±0.92	0.31 ±0.31	0.18 ±0.16	ns	0.12 ±0.20	ns	0.0	0.38	0.26	3.08	4.71
Aster conspicuus														
Foliage	2.89 ±2.12	2.17 ±1.13	0.43 ±0.50	0.29 ±0.31	0.20 ±0.34	0.96 ±0.03	0.0	0.0	0.43 ±0.20	0.33 ±0.17	0.0	0.0	5.34	3.03
Twigs	-	-	0.51 ±0.03	0.07 ±0.06	0.19 ±0.17	0.05 ±0.08	0.15 ±0.11	0.06 ±0.05	0.13 ±0.11	0.0	-	-	0.53	0.14
A. ciliolatus											0.43	0.0	0.43	0.0
Salix spp														
Foliage	3.68	1.59			2.56 ±1.84	0.90 ±0.82	-	-	0.50 ±0.70	0.58 ±0.30	0.0	0.0	3.68	1.81
Twigs	0.0	0.27			0.03 ±0.06	0.0			0.21 ±0.17	0.03 ±0.04			0.40	0.27
Amelanchier alnifolia														
Foliage	1.83 ±0.17	1.96	- -	- -	1.55	1.55 ±0.97			15.0	8.16 ±2.48	0.37	0.23	15.0	9.91
Twigs	5.33 ±7.36	5.97	-	-	0.49 ±0.34	2.01 ±1.31			3.01 ±1.07	2.11 ±0.04	-	-	10.5	5.97

Table 6-23 (Contd.)

Rosa acicularis														
Foliage	1.19	1.19	-	-	0.79 ±0.68	0.15 ±0.08			0.80 ±0.65	0.48 ±0.42	0.0	0.0	2.11	1.19
Twigs	-	-	-	-	0.46 ±0.53	0.07 ±0.08	-	-	0.16 ±0.27	0.14 ±0.13	-	-	1.07	0.25
Epilobium angustifolium														
Foliage	0.47	0.51	-	-	1.00 ±0.73	0.20 ±0.35	-	-	0.15 ±0.16	0.0	0.17	0.35	1.50	0.61
Twigs	-	-	-	-	0.18 ±0.18	0.05 ±0.09			0.21 ±0.24	0.04 ±0.06	-	-	0.47	0.15
Lonicera involucrata														
Foliage	0.58	-									0.26	0.0	0.58	0.0
Twigs	0.22	-											0.22	-
L. dioica														
Foliage											0.0	0.10	0.0	0.10
Viburnum edule														
Foliage											0.0	0.0	0.0	0.0
Corylus cornuta														
Foliage											0.0	0.15	0.0	0.15
Shepherdia canadensis														
Foliage											0.78	0.11	0.78	0.11
Spirea betulifolia														
Foliage											0.0	0.0	0.0	0.0
Cornus canadensis														
Foliage											0.0	0.0	0.0	0.0
C. stolonifera														
Foliage											0.0	0.0	0.0	0.0
Aralia nudicaulis														
Foliage											0.0	0.10	0.0	0.10
Vicia americana														
Foliage											0.11	-	0.11	-
Galium boreale														
Foliage											0.37	0.0	0.37	0.0
Castilleja miniata														
Foliage											0.0	0.0	0.0	0.0

HH = 4 kg hexazinone/ha treatment, LH = 2 kg hexazinone/ha treatment. Hexazinone was applied as PRONONE 10G.
*Values followed by SD are averages of 3 replicates.

Table 6-24. Metabolite-A (µg/g, dry wt.) in selected species during 1987-88 in samples from high hebcicide (HH, 4kg/ha) and low herbicide (LH, 2 kg/ha) treated plots

SPECIES	1987 SAMPLING										1988 SAMPLING		MAXIMUM	
	26 MAY		23 JUNE		22 JULY		23 AUGUST		2 SEPT		3 AUGUST			
	HH	LH	HH	LH	HH	LL	HH	LH	HH	LL	HH	LH	HH	LH
	(µg/g, dry wt.)													
Populus tremuloides														
Foliage (bulk)	0.05 ±0.09	0.0	0.0	0.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.15	0.50
'87 100% damaged on-plant foliage	0.0	-	0.27										0.27	-
"86 on-plant fol	0.0													
twigs	0.0	0.0	0.23 ±0.23	0.52 ±0.36	0.32 ±0.41	0.30 ±0.39	0.08 ±0.14	0.13 ±0.15	0.09 ±0.16	O.08 ±0.08	-	-	0.0 0.78	- 0.76
fresh litter	0.0	0.0	0.08 ±0.13	0.0	0.18 ±0.46	0.0	0.05 ±0.09	0.04 ±0.07	0.0	0.0	-	-	0.55	0.12
Calamagrostis canadensis														
'86 Growth	0.78 ±0.61	0.59 ±0.45	-	-	-	-	-	-	-	-			1.48	1.08
"87 Growth	1.07 ±0.90	1.07 ±0.67	0.83 ±1.43	1.33 ±2.07	0.46 ±0.62	0.13 ±0.23	ns	0.0	ns	0.0	0.11	0.46	2.48	3.72
Aster conspicuus														
Foliage	6.43 ±8.64	5.41 ±4.69	0.41 ±0.72	0.0	0.26 ±0.46	0.18 ±0.32	0.0	0.0	0.41 ±0.36	0.21 ±0.11	0.0	0.0	16.3	6.15
Twigs	-	-	1.41 ±0.17	0.32 ±0.06	0.37 ±0.33	0.12 ±0.21	0.28 ±0.18	0.13 ±0.12	0.33 ±0.14	0.0	-	-	1.57	0.37
A. ciliolatus														
Salix spp											0.75	0.0	0.75	0.0
Foliage	2.27	3.35			1.27 ±0.87	0.15 ±0.26	-	-	0.0	0.18 ±0.10	0.0	0.0	2.27	3.35
Twigs	0.21	0.82			0.0	0.0			0.53 ±0.37	0.10 ±0.02			0.95	0.82
Amelanchier alnifolia														
Foliage	0.0	0.0	- -	- -	0.27	0.11 ±0.18			0.14	0.09 ±0.12	0.25	0.0	0.27	0.32
Twigs	0.50 ±0.07	0.12	-	-	0.20 ±0.18	0.0			0.19 ±0.26	0.17 ±0.24	-	-	0.55	0.34

Table 6-24 (Contd.)

Rosa acicularis														
Foliage	0.40	0.0	-	-	0.12 ±0.21	0.10 ±0.18			0.21 ±0.19	0.09 ±0.08	0.0	0.0	0.40	0.31
Twigs	-	-	-	-	0.42 ±0.15	0.10 ±0.10	-	-	0.17 ±0.22	0.14 ±0.24	-	-	0.57	0.41
Epilobium angustifolium														
Foliage	0.0	0.54	-	-	0.0	0.0	-	-	0.05 ±0.09	0.0	0.19	0.82	0.19	0.82
Twigs	-	-	-	-	0.39 ±0.22	0.18 ±0.15			0.57 ±0.59	0.17 ±0.16	-	-	1.18	0.31
Lonicera involucrata														
Foliage	0.0	-									0.77	0.13	0.77	0.13
Twigs	0.35	-									0.35	-		
L. dioica														
Foliage											0.0	0.35	0.0	0.35
Viburnum edule														
Foliage											0.0	0.19	0.0	0.19
Corylus cornuta														
Foliage											0.0	0.41	0.0	0.41
Shepherdia canadensis														
Foliage											0.95	0.18	0.95	0.18
Spirasa betulifolia														
Foliage											0.0	0.0	0.0	0.0
Cornus canadensis														
Foliage											0.11	0.0	0.11	0.0
C. stolonifera														
Foliage											0.32	0.27	0.32	0.27
Aralia nudicaulis														
Foliage											0.0	0.24	0.0	0.24
Vicia americana														
Foliage											0.19	-	0.19	-
Galium boreale														
Foliage											0.78	0.0	0.78	0.0
Castilleja miniata														
Foliage											0.0	0.21	0.0	0.21

HH = 4 kg hexazinone/ha treatment, LH = 2 kg hexazinone/ha treatment, Hexazinone was applied as PRONONE 10G.
*Values followed by SD are averages of 3 replicates.

Environmental exposures to forest visitors and wildlife can occur when they come in contact with applied PRONONE 10G granules or leaves with residues of hexazinone, feed on vegetation (leaves, twigs, or fruit), or drink water after a severe runoff from treated areas. In the case of the present study on PRONONE 10G, foliage of plants from treated areas contained the most residues and are, therefore, considered to simulate the worst scenario for impact on consumers.

Pertinent LD_{50}, LC_{50}, and NOEL (no effect level) hexazinone concentrations have been extracted from several sources and presented in Table 6-25 (USDA 1984; WSSA 1983; Sidhu and Chakravarty 1990; Chakravarty and Sidhu 1987a, b). Hexazinone residues inlants can be present with or without visible herbicide damage to foliage. Residue levels being the highest during the first few months after application, most exposure to and consumption by wildlife fauna is expected during the first year. The monitored concentrations in vegetation are much below the acute toxicity levels in various organisms. The microorganisms and mammals feeding on dead or live plant parts are expected to consume, and may accumulate, extremely low concentrations of the hexazinone residues. The levels of accumulation will depend on the concentration in plants at the time of consumption, species of fauna feeding on vegetation, plant species, time of year, and total amount of affected vegetation consumed. It is important to know that hexazinone and its metabolites are not expected to accumulate in large quantities in the animal body. According to Rhodes and Jewell (1980), 93% of orally ingested hexazinone was excreted from rats in urine and feces within 72 hours, and no detectable residues remained. Extremely low or no hexazinone residues may be accumulated by consumers as a result of feeding on vegetation from hexazinone treated areas.

Table 6-25. Toxicity of hexazinone in selected organisms and detected maximum levels in foliage, twigs and leaf litter from boreal mixedwood

ORGANISM	REPORTED IN THE LITERATURE LC-50	LD-50	NOEL	MAXIMUM DETECTED CONC. µg/g IN THE PRESENT STUDY (DRY WEIGHT) FOLIAGE	STEM	LEAF LITTER
Residues in plants	-	-	-	11.2 µg/g	0.44 µg/g	7.83 µg/g
Invertebrates & microorganisms	-	-	< 10ppm	(Calamagrostis)	(Aster)	(Mixed)
Mycorrhizae fungi	-	-	< 10ppm (conc. in culture medium)	Water content (based on fresh weight) ranged from 56 to 80% in foliage, 47 to to 65% in twigs and 10 to 33% in leaf litter depending on the plant species and the time of collection during the year		
Bees	>60 µg/bee	-	60ug/bee caused 10% mortality in 48 hours			
Rats	-	4495 mg/kg	200 ppm in diet for 2 years (no carcinogenic effect)			
Fish	>100 ppm					
Birds	-	2258 mg/kg				
Rabbits		>2000 mg/kg				
Dogs	-	3400 mg/kg	1000 ppm			
Guinae pigs	-	860 mg/kg				
Fathead Minnow	274 ppm (in water)	-	-			
Bobwhite Quail	>10,000 ppm (8 days)	-	-			
Mallard ducklings	>10 000 ppm (8 days)					

Note: Values in this table are extracted from USDA (1984), WSSA (1983), Chakravarty and Sidhu (1987a), and Grande Prairie FRDA study.

Section 7

EFFECTS OF HEXAZINONE ON MICROORGANISMS

It is essential to know the direct and indirect effect of hexazinone on microorganisms responsible for decomposition of organic matter and mycorrhizal fungi associated with roots of conifer crop species. A review of the available literature on the effect of hexazinone on micro-organisms including mycorrhizae associated with boreal crop trees revealed no or inadequate information on this aspect prior to the Grande Prairie study. A comparison of hexazinone degradation in sterile and nonsterile soil concluded that hexazinone is degraded by microorganisms (Rhodes 1980a). He found that after 80 days of incubation 75% of the applied radioactivity evolved as $^{14}CO_2$ suggesting total degradation of the triazine ring of hexazinone to evolve CO_2. Rhodes, Krause and Williams (1980) reported no decrease in fungal or bacterial populations in soils with 10 ppm (w/w, oven dry basis) of hexazinone in three agricultural soils. No toxicity to fungi was detected at treatment rates up to 100 ppm of hexazinone. Hexazinone at 5 and 20 ppm rate had no effects on soil-nitrifying bacteria in two agricultural soils for a 5-week test period. According to Neary, Bush and Grant (1986), the herbicide may have a stimulatory effect on nitrifying bacteria at very low concentrations.

A two-year study was undertaken to investigate the effects of three herbicides (glyphosate, hexazinone, and triclopyr) on the growth of mycorrhizal fungi associated with white spruce and lodgepole pine (Chakravarty and Sidhu 1987a, b; Sidhu and Chakravarty 1990).

In vitro growth tests with glyphosate (Roundup), hexazinone (liquid Velpar L. and granular Pronone 5G) on five species of ectomycorrhizal fungi (*Hebeloma crustuliniforme, Laccario laccata, Thelephora americana, T. terrestris*, and *Suillus tomentosus*) showed varied species sensitivity to different concentrations of herbicides. Fungal growth was significantly ($P = 0.05$) reduced particularly at concentrations above 10 ppm. Garlon with triclopyr as a.i. was the most toxic of the four herbicide formulations. The toxicity index for herbicides were as Garlon (a.i. triclopyr) >Velpar L (ai hexazinone) >Roundup (a.i. glyphosate) >Pronone 5G (a.i. hexazinone). Relative sensitive index of mycorrhizal fungi were S. tomentosus > T. americana > H. crustiliniforme >L. laccata >T. terrestris.

In another study, effects of hexazinone (Pronone 5G) at three levels of application (equivalent to field rates of 1, 2, and 4 kg a.i./ha) on the seedling growth and mycorrhizal development in lodgepole pine (*Pinus contorta* Doug. var. *latifolia* Engelm.) and white spruce (*Picea glauca* [Moench] Voss) were investigated under greenhouse conditions. Both conifer species responded similarly except that phytotoxic effects were more intense in pine than in spruce. There was an initial reduction in seedling growth and mycorrhizal development at 1 kg a.i./ha rate; however, a recovery to control conditions occurred after 4 months. At application rates of 2 and 4 kg a.i./ha there was significant ($P = 0.05$) reduction in seedling growth parameters and mycorrhizal development compared with control and 1 kg a.i./ha treatment. Though within 6 months after planting, seedling growth and mycorrhizal infections improved significantly ($P = 0.05$) over the initial reduction, these parameters still remained significantly lower than the control and 1 kg a.i./ha treatment (Chakravarty and Sidhu 1987b).

The study under natural conditions showed that the effects of hexazinone on mycorrhizal and seedling growth under field conditions were of significance only at the 4 kg/ha rate and were of much less intensity than under greenhouse conditions. This was possibly because of the mop-up effect of the competing vegetation and some mobility of the herbicide from surface to deeper horizons (Sidhu and Chakravarty 1990). Phytotoxic as well as fungitoxic effects were less intense in the field than in

growth chamber and greenhouse conditions. Application of hexazinone under the field condition did not result in mortality of the mycorrhizal inoculum in the soil. Seedlings of pine and spruce that were free of mycorrhizal infections at planting in hexazinone-treated plots, formed well-developed mycorrhizae within 2 months after planting (Sidhu and Chakravarty 1990). Based on the results of the present study, it is concluded that no long-term negative effect of hexazinone is expected on the survival of mycorrhizal inoculum and development of mycorrhizal infections in white spruce and lodgepole pine at 1-4 kg/ha rates under field conditions.

Section 8

EFFECT OF HEXAZINONE ON NUTRIENT STATUS OF FOLIAGE AND SOIL NUTRIENT DYNAMICS

8.1 FOLIAR NUTRIENTS

8.1.1 Introduction

Foliar nutrient status has often been used as an indicator of the nutrient status of site or changes in site conditions by vegetation removal, application of fertilizers, site drainage, and other changes in physical factors. Not much information is available on the effect of herbicide application on nutrient status and soil nutrient dynamics in boreal forest. Seasonal nutrient variations have been reported by McColl (1980) in trembling aspen, in tamarack by Tilton (1976) and in tundra plants species by Chapin III et al. (1980). Grigal, Ohmann, and Brander (1976) studied the biomass and nutrient dynamics in tall shrubs from Minnesota. Tappeiner and Alm (1975) reported that the undergrowth added significantly to the total weight of litter-fall and amounts of the different elements. The rate of decomposition of leaf litter depended on the species of the undergrowth and type of stands.

The management of vegetation by mechanical or chemical methods is expected to reduce vegetation cover of target as well as nontarget species. As a result there is an expected reduction in total litter-fall, change in seasonal pattern of litter-fall and alteration in the quality of foliar nutrients.

The foliar nutrient study was designed to meet the following objectives:

1) To establish reliable estimates of seasonal and year-to-year hexazinone-related changes in the major elements in foliage of selected dominant species (e.g., *Populus tremuloides, Aster conspicuous, Calamagrostis canadensis, Epilobium angustifolium*) in hexazinone-treated and control plots of the Grande Prairie study.

2) To establish reasonable estimates of broad changes in foliar nutrient status of a number of common species over at least two growing seasons following the herbicide application.

3) To determine the differences among species in their nutrient status and variations within species in selected dominant species.

4) To compare nutrient status of foliage and twigs of selected herbaceous and woody species in the herbicide-treated and control plots (e.g., *Aster conspicuus, Amelanchier alnifolia, Viburnum edule, Populus tremuloides, Rosa acicularis, Shepherdia canadensis, Corylus cornuta, Cornus stolonifera*).

8.1.2 Material and Methods

Composite foliar samples for all species were collected the same way at all sampling times during 1987 to 1989 (Appendix C). The samples were collected from two corridors between the rows of 5 m x 5 m permanent plots (Fig. 4-3). The foliage and twigs were collected from the top 20 cm growth of the live stems at 20 sampling points at regular intervals along a traverse through the two corridors.

The composite samples were dried at 70°C overnight and ground with a Wiley mill to pass through 20-mesh screens.

The ground foliage and leaf-litter samples were oven-dried at 70°C overnight before analysis, and 0.500 g of each oven-dried sample was digested using a microwave digestion technique (Kalra, Maynard, and Radford 1989). The foliar digest was further processed for total elemental (Ca, Mg, Na, K, Mn, Al, Fe, P and S) analysis by inductively coupled plasma-atomic emission spectrometer analysis (Kalra, Maynard, and Radford 1989). For total N, the samples were digested with H_2SO_4 using a digestion block (Bremner and Mulvaney 1982) followed by distillation and titration using the Kjeltec Auto 1030 Analyzer (Tecator 1985).

8.1.3 Results and Conclusions

The nutrient status in foliage and stem over the period of May 1987 to July 1989 in *Aster conspicuus, Populus tremuloides, Calamagrostis canadensis*, and *Epilobium angustifolium* and from summer 1987 to August 1988 in other species is summarized in Appendix C.

1) The results of several species from control areas for May 1987 and July 1989 revealed that the variations among replicates (±S blocks) and within species for a single collection time was to up to 10% of the mean for Ca, Mg, K, and total N; and 10 to < 20% for P and S. The values for Na, Mn, Al, and Fe were extremely variable and it is not possible to make any meaningful comments.

2) Seasonally in all species in general, Ca in foliage increased from spring to fall; K, P, N, and S peaked in the early summer and decreased toward fall; Mg did not show any definite trends. The seasonal trends emerging from the present data are similar to those reported in other species and vegetation types.

3) Seasonal and year-to-year variations are large among species in their foliar Ca, Mg, K, P, S, and N status. Some species showed specific affinities to certain elements. For example, herbaceous species such as *Aster, Galium*, and *Castilleja* were identified as high K-accumulators; *Cornus canadensis* as a high Ca-accumulator; and species like *Calamagrostis canadensis, Amelanchier alnifolia*, and *Epilobium angustifolium* as high P-accumulators. The changes in these species could play a significant role in the nutrient cycling on sites that undergo treatments which alter these species' growth and dominance significantly. These changes could be of significant magnitudes during the first 2 years following treatments.

4) The concentrations of elements in stems (without leaves) were always lower than those in the foliage. In woody species (*Populus, Rosa, Amelanchier*) the ratios of twig:foliar concentrations were 1:2 to 3:5 for Ca, 1:3 to 1:5 for Mg, 1:2 to 1:5 for K, 1:3 to 1:6 for P, 1:3 to 1:6 for P, 1:3 to 1:7 for S and 1:2 to 1:5 for total N. These differences in nutrient concentration in twigs and foliage of the same species were less pronounced in herbaceous species such as *Aster conspicuus*.

5) The application of hexazinone as PRONONE definitely affected the foliar nutrient status in a number of species monitored for the purpose. The changes and trends are summarized as:

   (i) The fall application of hexazinone resulted in a general increase of K, P, S, and N. The increase was much more pronounced in 4 kg hexazinone/ha rate than in the 2 kg/ha rate.

(ii) Earlier in the season, concentrations of Ca and Mg were much higher in foliage of most species from herbicide-treated plots; however, before the abscission of foliage in the fall, Ca levels of foliage from control plots were much higher than those from the treated plots. Mg did not show any definite pattern in the fall.

(iii) The intensity of the effects of the herbicide declined by the end of the second growing season following the herbicide application, but the trends described under 5i and 5ii were still identifiable. The detailed study of four species, *Populus tremuloides, Aster conspicuus, Calamagrostis canadensis*, and *Epilobium angustifolium*, clearly showed that there were no significant differences in the nutrient status of foliage from control and treated plots in 1989.

It can be concluded from the monitoring of the nutrient status in foliage of several species that the greatest changes due to hexazinone occurred during the first growing season following the fall application and continued until the end of the second growing season. These differences practically disappeared by the end of the third growing season following the herbicide application. The changes included lower Ca, and elevated levels of K, P, S, and N in the herbicide-affected foliage. The extent of change in the concentration of these elements in the soil as a result of nutrient changes in foliage would depend on the net change in concentrations of all species in combination with the change in amount and timing of litter-fall and the relative contribution to the leaf litter from each affected species. Overall gross changes in nutrient status of foliage are reflected in the nutrient dynamics in soils (Section 8.2).

8.2 SOIL NUTRIENT DYNAMICS[30]

8.2.1 Introduction

Herbicide research has emphasized efficacy on target species, residue degradation, water quality, and possible toxicological impacts (Neary 1988). Little attention, however, has been paid to the impact of herbicide applications on the soil nutrient dynamics of forest ecosystems (e.g., Vitousek and Matson 1985). The limited information available indicates, in general, total losses of nutrients in streamwaters have increased following herbicide applications; however, the losses have not been considered to pose a threat to site nutrient depletion (Vitousek and Melillo 1979; Krause 1982). Most of these studies looked only at losses of N, particularly NO_3-N by leaching. Soluble organic N leaching losses, gaseous N losses, and N concentrations in the soil have been measured in only a few studies (Vitousek and Matson 1985; Robertson et al. 1987; Kimmins 1987). Even fewer studies have monitored elements other than N (e.g., Likens et al. 1970; Neary et al. 1986).

Herbicides can be used with minimal physical disturbance to the soil; however, there is the potential for soil nutrient losses where the herbicide kills a large portion of the vegetation. The effects of herbicides on biogeochemical cycles of soil nutrients could also directly affect soil microbial populations and thus alter the mineralization of elements such as N, P, and S. Indirect effects of herbicides could result in changes to litter-fall quantity and quality. The objectives of the present studies were

---

[30]Section 8.2 Contributed by Dr. D. Maynard, Northern Forestry Centre, Edmonton. Based on preliminary results of his A-base Study NOR-07-05 carried out on the Grande Prairie FRDA study area.

1) to document changes occurring to soil nutrients as a result of hexazinone applications under operational field conditions,

2) to determine what processes were involved in the changes to soil nutrients as a result of hexazinone applications, and

3) to determine the possible implications the observed changes could have to site productivity.

8.2.2 Materials and Methods

The study was done in three separate components consisting of

1) monitoring the soil in the 0, 2, and 4 kg ai/ha treatments of Block 2, Method II of the operational field plots (Section 4.2).

2) a small-scale field experiment with a greater sampling intensity and field measurements of litter-fall, leaching from surface organic horizons (LFH), and estimates of decomposition rates; and

3) a growth chamber study to determine the effect of hexazinone on the decomposition and mineralization of nitrogen, phosphorus, and sulfur.

Details of the small-scale field experiment and the growth chamber study are not presented in this report. The analyses from these studies are being completed and journal publications are in preparation. The results of the small-scale field experiment and the growth chamber study will be referred to only as they pertain to the results of the operational plots.

The plot design and herbicide application were described earlier (Section 4.2). Samples were collected from the 0, 2, and 4 kg ai/ha treatments of Block 2 only. In each treatment adjacent to the vegetation quadrats fifteen 3 m × 3 m soil subplots were set up. Within each subplot two soil pits were dug. The soil was sampled by horizon to the Bnt(gj). In most pits that consisted of four horizons; a LFH (surface organic horizon), Ah or Ahe, Ae, and Bnt(gj). In some pits the Ah (Ahe) horizon was not present. Samples were collected prior to the herbicide application, on July 28-30, 1986 and for two years following the herbicide application, on August 17-18, 1987 and August 30-31, 1988. The resampling in 1987 was delayed until after significant amounts of litter had fallen as a result of the herbicide application.

The soils were handled the same for all sampling times. After sampling, the soils were kept cool and transported back to the laboratory and frozen (-20°C) until the analysis was to be done. The LFH material was thawed, homogenized in a Waring blender and subsamples weighed out moist for pH and extractable N, P, and S. Subsamples were air-dried for cation exchange capacity (CEC) and exchangeable cations and for total elemental analysis (N, Ca, Mg, Na, K, Mn, Al, Fe, P, and S). The air-dried samples were crushed and mixed prior to weighing for CEC and exchangeable cations. For total analysis, air-dried subsamples were further ground in a Wiley mill to pass through a 20 mesh sieve.

The pH of the LFH was measured in 0.01 M $CaCl_2$ solution (2:1 solution to moist soil ratio after being brought to a paste). In the mineral soils a 2:1 0.01 M $CaCl_2$ solution to soil ratio was used. The moisture content of the soils was determined after oven-drying the soils (LFH or mineral) in a forced air oven at 105°C for 24 h.

Ammonium (NH_4) and nitrate (NO_3) were determined in a 2 M KCl extract (approximately 20:1 solution to soil ratio, oven-dried weight (odw) basis) by a Technicon autoanalyzer II system (AA II). Ammonium was determined by the indophenol blue colorimetric technique (Technicon 1973) and nitrate was determined colorimetrically using the copperized cadmium (Cd) reduction method (Technicon 1971). The Cd reduction technique includes nitrite (NO_2) plus NO_3.

Total extractable S of the LFH material was determined in 0.01 M NH_4Cl extract (approximately 20:1 solution to odw soil ratio) by inductively coupled plasma argon emission spectrometer (ICP-AES) (Maynard et al. 1987). Total extractable P was determined in Bray 1 (0.03 M NH_4F and 0.025 M HCl) extract (approximately 10:1 solution to odw soil ratio) by ICP-AES (Olsen and Sommers 1982).

Cation exchange capacity and exchangeable cations were determined by extraction with unbuffered 1.0 M NH_4Cl on a mechanical vacuum extractor (Holmgreen et al. 1977). Exchangeable cations were determined in the extract by ICP-AES. The NH_4 for CEC was determined by distillation using a Tecator 1030 distillation apparatus after displacement of the NH_4 from the exchange sites by NaCl.

Total N in the LFH material was determined by Kjeldahl digestion (no pretreatment) and N in the digest determined by an automated Tecator 1030 distillation apparatus (Bremner and Mulvaney 1982). Total N in the mineral soil was digested the same as for the LFH; however, because of the low N concentrations in mineral soils, N in the digest was determined colorimetrically by AA II (Technicon 1971).

Total Ca, Mg, Na, K, Mn, Al, Fe, P, and S in the LFH were determined by ICP-AES following wet digestion (HNO_3-H_2O_2-HCl) by microwave oven (Kalra et al. 1989). Total elemental analyses (other than N) in the mineral soils were determined by ICP-AES following wet digestion (HNO_3-$HClO_4$-HF-HCl) by an aluminum block digestor (McQuaker et al. 1979).

8.2.3 Results and Discussion

Total elemental concentrations of the LFH from 1986 to 1988 are given in Table 8-1. There were some differences for several elements among treatment plots prior to the herbicide application. This was most likely related to the slope location of the plots (i.e., the control was on the top of the slope and the two treated plots were mid-slope).

The study site was clearcut in 1983 and the nutrient balance would have been disrupted. Decreases in the total N, S, and Ca concentrations of the control plot LFH from 1986 to 1988 indicated the nutrient balance was not static and was still changing because of the clearcut disturbance. Increasing amounts of these elements (N, S, and Ca) could have been tied up in the aspen biomass (which was also increasing) both aboveground and in roots, thus reducing the total nutrient concentrations in the soil.

Total N and S concentrations in the LFH showed the greatest change as a result of the herbicide application. In 1986, prior to the herbicide application, total N and S of the LFH were the highest in the control plot. In 1987 and 1988, after the herbicide application, N and S concentrations were higher in the LFH of the 4 kg ai/ha treatment (Table 8-1). The N concentration in the LFH of the herbicide-treated plots remained constant from 1986 to 1988 but decreased by 5 g/kg in the control. Similarly S concentrations remained the same or increased slightly in the treated plots but

Table 8-1. Total nutrient concentrations (g/kg) in the LFH of the control, 2 and 4 kg ai/ha treatment plots, Block 2 for 1986, 1987, and 1988 (mean ± 95% confidence limits)

		Herbicide rate kg ai/ha		
Nutrient	Year	0	2	4
N	1986	18.6 ± 1.0	16.9 ± 1.2	15.4 ± 1.4
	1987	12.3 ± 1.0	14.0 ± 0.9	14.5 ± 1.4
	1988	13.8 ± 1.2	14.8 ± 1.0	15.8 ± 0.9
S	1986	1.50 ± 0.09	1.43 ± 0.12	1.25 ± 0.12
	1987	1.28 ± 0.13	1.30 ± 0.09	1.42 ± 0.15
	1988	1.23 ± 0.11	1.37 ± 0.09	1.44 ± 0.08
Ca	1986	19.0 ± 1.5	17.3 ± 1.6	15.3 ± 1.8
	1987	17.0 ± 2.0	14.8 ± 1.2	16.7 ± 1.9
	1988	15.1 ± 1.5	15.7 ± 1.3	16.5 ± 1.3
Mn	1986	1.04 ± 0.12	0.87 ± 0.12	0.93 ± 0.14
	1987	1.30 ± 0.17	0.98 ± 0.12	0.91 ± 0.11
	1988	0.95 ± 0.13	0.82 ± 0.14	0.66 ± 0.10
P	1986	1.29 ± 0.06	1.25 ± 0.07	1.22 ± 0.07
	1987	1.42 ± 0.09	1.26 ± 0.08	1.41 ± 0.11
	1988	1.14 ± 0.07	1.22 ± 0.09	1.27 ± 0.06
Mg	1986	2.38 ± 0.08	2.48 ± 0.09	2.72 ± 0.12
	1987	2.56 ± 0.10	2.43 ± 0.10	2.82 ± 0.13
	1988	2.26 ± 0.11	2.50 ± 0.11	2.60 ± 0.10
K	1986	1.65 ± 0.20	1.52 ± 0.10	1.82 ± 0.14
	1987	1.66 ± 0.15	1.40 ± 0.10	1.56 ± 0.10
	1988	1.83 ± 0.16	1.78 ± 0.20	1.74 ± 0.20

decreased approximately 0.30 g/kg in the control. The N and S concentrations of the LFH in the 2 kg ai/ha treatment were intermediate between the control and 4 kg ai/ha for all years (Table 8-1).

Total Ca in the LFH also showed a similar pattern to N and S concentrations as a result of the herbicide application (Table 8-1). Calcium concentrations in the LFH of the 4 kg ai/ha remained constant from 1986 to 1988 while the Ca concentration in the control decreased from 19.0 to 15.1 g/kg. The only other element in the LFH that showed any change following the herbicide application was total Mn; however, the changes were the opposite to N, S, and Ca. The Mn concentration of the LFH in the control did not change while the concentrations of Mn in the LFH of the 4 kg ai/ha decreased by 30% (approx. 0.3 mg/kg).

Extractable NH_4-N and NO_3-N in the LFH for 1986 and 1987 are given in Table 8-2. Similar to the total N concentrations, extractable NH_4-N and NO_3-N of the LFH were higher in the herbicide treated plots than the control in the year following herbicide application. Prior to the herbicide application, the NH_4-N and NO_3-N concentrations of the LFH in the herbicide- treated plots were the same or less than in the control, respectively (Table 8-2). Ammonium concentrations decreased from 1986 to 1987 in all treatments; however, the decrease was much greater in the control (196 to 59 mg/kg; Table 8-2). Nitrate in the LFH of the control also decreased from 1986 to 1987, but in the herbicide treated plots NO_3-N increased from virtually zero to 6.3 and 7.2 mg/kg in the LFH of the 4 and 2 kg ai/ha plots, respectively. Extractable S concentrations in the LFH were low for all treatments in both 1986 and 1987. The changes between 1986 and 1987 among treatments were small and did not appear to follow the same pattern observed for the total S concentrations; however, extractable S accounted for < 2% of the total S concentrations in the LFH.

In a growth chamber study (results from this laboratory, publication in preparation), amounts of extractable NH_4-N, NO_3-N, SO_4-S, and PO_4-P released from LFH material were not affected by hexazinone. Hexazinone applied at twice the field rate (8 kg ai/ha) had no effect, either positive or negative, on the soil microbial population responsible for N, S, and P transformations. Other processes such as changes in litter-fall quality or a reduction in nutrient uptake by the vegetation were more likely responsible for changes in nutrient concentrations of the LFH observed in the operational plots.

Analysis of the litter-fall from the small-scale field study adjacent to the operational plots indicated the litter that fell early in the growing season as a result of the herbicide application was higher in N and S than the litter of the control that fell during normal senescence. Calcium, on the other hand, was lower in the litter from the herbicide-treated plots than from the control (results from this laboratory, journal publication in preparation). The changes observed in litter- fall quality as a result of the herbicide application at the small-scale field study support the hypothesis that litter-fall quality was affecting the nutrient concentrations of the LFH in the herbicide-treated plots. The higher extractable NH_4-N and NO_3-N concentrations of the LFH in the herbicide-treated plots compared with the control (Table 8-2) indicated that lower uptake of available N due to less vegetative cover could also be important in the nutrient balance of these soils. Therefore, changes to litter-fall quality and reduced uptake or removal of nutrients by the vegetation were the most likely processes affecting N, S, and Ca concentrations of the LFH in the herbicide-treated plots, particularly the 4 kg ai/ha.

Table 8-2. Extractable concentrations (mg/kg) in the LFH of the control, 2 and 4 kg ai/ha treatment plots, Block 2 for 1986 and 1987 (mean ± 95% confidence limits)

		Herbicide rate kg ai/ha		
Nutrient	Year	0	2	4
NH_4-N	1986	196 ± 22	229 ± 26	186 ± 28
	1987	59 ± 8	102 ± 15	139 ± 21
NO_3-N	1986	3.6 ± 2.0	0.2 ± 0.2	0.1 ± 0.2
	1987	1.1 ± 0.6	7.2 ± 1.4	6.3 ± 1.8
S	1986	9.0 ± 3.7	29.2 ± 5.3	24.4 ± 4.0
	1987	14.0 ± 3.3	19.0 ± 3.8	18.2 ± 4.2
P	1986	90 ± 10	125 ± 12	110 ± 15
	1987	64 ± 10	71 ± 10	98 ± 17

8.2.4 Conclusions

The preliminary results suggest that the nutrient balance (particularly N, S, and Ca) has been altered up to 2 years after herbicide application; however, the implications of herbicide applications on site productivity are not clear. The results of the study were complicated because of the dynamic nature of the site. The study area was clearcut in 1983, and changes to the vegetation cover and nutrient balance of the soils were still occurring in 1988. Superimposed on this was the addition of the herbicide; however, it is evident from the initial results that the herbicide application has impacted on the nutrient concentrations of the soil. The implications of these changes on long-term nutrient depletion and site productivity can not be determined at this time for two reasons: the analysis has not been completed and therefore not all the information is available (e.g., mineral soil data), and it is very difficult to extrapolate changes that occur over 2 years to long-term productivity because of the large temporal (year-to-year) variability.

Section 9

SUMMARY AND RECOMMENDATIONS

The forest vegetation management project was initiated within the Canada-Alberta Forest Resource Development Agreement (FRDA) under Project Activity B, subprogram B.3, (Forestry Research, Development and Demonstration) as a joint undertaking by Forestry Canada, Northwest Region, Northern Forestry Centre and by the Research and Reclamation Branch of the Alberta Forest Service with shared roles in planning, management, and implementation among other cooperators. The project is comprised of three study components; silviculture: environment, and economics. In addition, a non-FRDA study on the impact of vegetation management methods on small mammals was carried out by Penner and Associates (Penner 1990). This report presents information available to date (1985-89) on the Environmental Impact Assessment Component of selected methods of site preparation and crop release in an area designated for softwood conversion in Alberta.

The **objectives** of the environmental component were to: 1) evaluate the impact of PRONONE 10G and other vegetation management methods on vegetation changes in structure, composition, and dynamics of vegetation; 2) develop environmental impact and residue and fate data for hexazinone as PRONONE 10G, including evaluation of herbicide application technology and development of residue-analysis techniques; 3) and determine the influence of hexazinone application and other silvicultural practices on the long-term stability of nutrient balance and biological control (including mycorrhizae) of tree nutrition.

The **study** covered two aspects of vegetation management, **Crop Release** (Method I) and **Site Preparation** (Method II). Site preparation treatments were applied in August 1986 and May 1987 to an aspen-dominated area about 21 km south of the Grande Prairie Pulp Mill within the Proctor and Gamble Forest Management Agreement area. Crop release treatments were applied in May 1989. Results presented in this report for most part are applicable to the methods of site preparation involving fall application of PRONONE 10G and spring application of mechanical methods. The study area was located on a 3-year-old cutover within the mixedwood section of the boreal forest region. Aspen regrowth (1-2 m tall) formed an almost continuous canopy. **Mechanical (double-disking and disk-trenching), chemical (hexazinone at 2 and 4 kg/ha as PRONONE 10G)**, and their combinations, and manual (brushsaw) methods were used for site preparation and crop release. In both cases, **white spruce** (plug +1) and **lodgepole pine** (container grown) were planted in May 1987 following mechanical treatments. The granular herbicide was selected because of least off-site drift potential, little direct contact with the operators with the active ingredient, unrestricted time of application opportunity from spring to fall, potential to control a broad spectrum of vegetation, and its continued activity in soil for at least 2 years.

Vegetation changes were assessed as changes in phenological development and symptomology of herbicide damage in common species, stem density of woody species, and cover by vegetation strata (tall shrub, >1.5 m; medium shrub, 50-150 cm; forbs; graminoids; and mosses and bryophytes. Pretreatment assessment of vegetation concluded that up to 20% of foliar damage can result from insect and disease infestations for short durations. Aerial application of PRONONE 10G in the fall of 1986 did not produce any visible symptoms on vegetation in 1986. Low herbicide (LH) treatment (2 kg hexazinone/ha) had a marginal effect on woody and herbaceous species except *Calamagrostis canadensis* (which was heavily impacted) for short periods and was an ineffective treatment for vegetation management when used as fall application. The 4 kg/ha rate produced typical herbicide damage symptoms ranging from wilting, chlorosis, necrosis, senescence, and defoliation to final

mortality. The intensity of damage varied with the plant species, age of individuals, stem density and above all the distribution of the PRONONE granules. The species were categorized according to their phenological response to the herbicide. The herbicide damage peaked at the end of the second growing season following the herbicide application, followed by recovery in health and cover of vegetation during the third growing season. **It is recommended that in assessing the effect of PRONONE 10G on vegetation control, 1st year assessments can be skipped for effective use of resources in high-cost environmental assessments. Where effective control of woody species is desired, 2 kg hexazinone/ha rate should be excluded in a fall application.** Spring application in a controlled (hand application) experiment in very small plots suggests that effective control of woody stems at 2 kg/ha rate can be achieved for the first year. The effect of the herbicide depended both on the physiological state of the plant species, and on the rate and distribution of the herbicide.

Pretreatment density of all woody stems and aspen alone varied within treatments and between treatment plots (43 360 to 92 788 stems/ha, CV of 28 to 78%). Aspen accounted for over 75% of the stem density. The effects of the treatments reached their peak by the end of 1988. The efficacy of different treatments in controlling woody vegetation was in the order of double-disking (DD) > 4 kg hexazinone and disk-trenching (HH+DT) > 4 kg hexazinone/ha (HH) > 2 kg hexazinone/ha and disk-trenching (LH+DT) > 2 kg hexazinone/ha (LH). The practical difficulties in applying the same intensity of a treatment to all sampling plots within a treatment plot and all replicates within a treatment, superimposed on the existing variability among subplots and treatment plots, made the interpretation and analysis of vegetation data difficult. LH treatment (fall application) alone did not reduce the woody stem density and is **not recommended** for vegetation management. Depending on the required level of control of woody vegetation and species to be controlled, HH+DT, HH, or LH+DT can be selected for a 60, 50 or 40% control of woody stems. **It is recommended that the woody stem control data be analyzed in relation to the establishment and growth of crop seedlings for the 3rd, 5th, and 8th years after the site and crop release treatments of 1986 and 1989 (1989/90, 1991/92, and 1995/96) and cost-benefit analysis of treatments be performed to establish practical guidelines for vegetation management.** An analysis of the 3-year growth data (Todd and Brace)[31] for white spruce and lodgepole pine concluded that HH or HH+DT were the most effective treatments for increments in the mean growth of white spruce (HH+DT > HH > LH+DT for both volume and height) and lodgepole pine seedlings (HH+DT > DD > HH for volume; HH > DD > HH+DT for height).

The study area was rich in plant species. Over 110 plant species occurred in the study area. Species richness, like the stem density, varied widely (CVs of 13-45%) within plots, within treatments, and within years. There was no apparent loss of species as a result of herbicide treatment. In over 60% of the 57 leading species, there was no significant year-to-year change in frequencies in control plots. Twenty-five percent of species showed insignificant increase and another 10% exhibited insignificant decrease in frequency in control plots. Seventy percent of the leading species decreased significantly in frequency during the first growing season following herbicide application but recovered significantly in second and third growing seasons in both LH and HH plots. The recovery was faster in LH plots.

The changes in vegetation cover were considered at various levels of vegetational organization (by strata, individual species, and species complexes). Natural changes in vegetation were operative in control areas resulting in an increase in cover of tall shrubs by one cover class and no change in

---

[31]P. Todd and L. Brace. 1990. A summary of third-year results from the FRDA forest vegetation management project, Canada-Alberta Agreement.

medium shrub stratum, or forbs, graminoids, mosses and bryophyte strata. There was a general shift toward the cover classes with medians of 15-45% in medium shrubs and 35-65% in forbs. The LH treatment (2 kg hexazinone/ha) had no overall measurable effect on the cover of medium shrub, forb, and moss strata. Tall shrub cover increased by two cover classes (20%) while graminoid cover decreased by one cover class (10%). The HH treatment resulted in a general decrease of medium shrubs and forbs by one (10%) and three (30%) cover classes respectively. The effect on graminoids was similar to that of the LH rate. Though there was a recovery in medium shrub, forb, and graminoid cover in the second growing season following the treatment, the median cover values remained lower in 1989 than in 1986. In general, the cover data support the observations on stem density. The mechanical treatments alone (DD, DT) or in combination with herbicides resulted in partial or complete removal of surface soil horizons along with the vegetation cover. Controls and herbicide-treated plots exhibited less than 20% disturbance in over 80% of plots compared with 20-60% disturbance in disk-trenched and 80-100% terrain disturbance in double-disked plots. **It is recommended that all cover data and terrain disturbance data be related to crop-seedling growth and possible losses of soil and soil nutrients before making final recommendations on vegetation management by mechanical methods alone or in combination with herbicides.** The cover changes in individual leading species followed the same pattern as changes in vegetation cover by strata. Data on a large number of species is presented in case changes in particular species are to be considered for their non-forestry uses.

Consideration of the vegetation changes as species complexes concluded that there were significant changes in community structure and dynamics expressed as successional trends following different pathways in control and herbicide-treated plots. **It is recommended that the vegetation be sampled for study of the successional trends in the future at 5 and 8 years after treatments and relate these changes to nutrient dynamics in soil and crop-seedlings growth to assess the long-term vegetation changes due to vegetation management.**

The study emphasized enhancing information on the environmental implications of the use of the herbicide hexazinone (primarily its granular formulation, PRONONE 10G) ranging from evaluation of the application technology, residue analysis techniques, to physical characteristics, and environmental fate of hexazinone when applied as PRONONE.

Two formulations of hexazinone, a granular PRONONE 10G and a liquid VELPAR L, were examined on a main study site south of Grande Prairie and several smaller sites elsewhere in Alberta between 1986 and 1989. **Application of granular PRONONE 10G** was studied by using an aerial applicator (an Isolair bucket attached to a helicopter) and two ground applicators, including a truck-mounted ACE rotary spreader and a tractor-mounted Granul-Air applicator. Among the three methods, the aerial applicator produced the best results. There was little cross-wind effect on the distribution of granules and resulted in limited or no off-target drift. However, large variations were found at a scale between 1 and 5 m spacing within the application swaths, indicated by the variation between 0 and 100% vegetation control observed in 1 × 1 m and 5 × 5 m vegetation survey plots and soil core samples for hexazinone residues and nutrients. **It is recommended that application technologies should be developed further to deliver uniformly and correctly calibrated amounts to ensure homogeneous distribution of granular herbicides at the ground level.**

Studies resulted in the development of new methods for the application of liquid herbicides (i.e., Velpar L) and the soil sampling and analysis of hexazinone and metabolites, including 1) a logarithmic sprayer to provide a continuous reduction of application rates over one swath, 2) a soil sampling method for zero-time residues, and 3) a less labor-intensive analytical method for the determination of residues of hexazinone and its major metabolites in soil and vegetation samples. The performance

of the logarithmic sprayer was sufficiently accurate when there were three or more replicates. **It is recommended that the logarithmic sprayer be used in small plot, dosage-response trials for the liquid formulations of forestry herbicides with three or more replicates.** Reliable monitoring of herbicide deposition and residue levels is a prerequisite for efficacy and environmental studies. Residue levels detected in soil samples, taken immediately (at zero-time) or shortly after application, are often found to be lower than both the rate of application and the residue levels in soil samples taken several days later. A new glass-jar method was established to solve this problem. **It is recommended, in estimating the dissipation rate of a liquid herbicide in soils, that the glass-jar sampling method be used between zero-time immediately after spraying and the first rainfall, followed by the conventional corer method for subsequent soil samplings.** The conventional analytical method for hexazinone and its metabolites is reliable but labor-intensive, time-consuming, and expensive for soil samples, and is insufficient for cleanup of the aspen foliage and other vegetation samples before gas chromatographic (GC) analysis. The disposable microcolumn method coupled with an improved solvent system provided reliable results similar to the conventional method but required only one-third amounts of both solvent and labor in sample cleanup, and it improved stability for soils and capability for vegetation samples in GC analysis. **It is recommended that this new analytical method be submitted to the National Check Sample Program of the Canadian Association of Pest Control Officials (CAPCO) for interlaboratory evaluation and, if found reliable, be transferred to analytical laboratories, researchers, and the federal and provincial regulatory agencies.**

The physical-chemical characteristics of the granular formulation of hexazinone, PRONONE 10G, were examined in both the laboratory and the field. Large variations were observed in granule size and weight. The laboratory study on the release rate of hexazinone (a.i.) indicated that a maximum of 50 mm rain-equivalent is required to release 90% of a.i. within 4 hours. Under field conditions, the release rate depended on both the amount of rainfall and the time of exposure (i.e., 1 mm rainfall is required in a 7-day exposure for 90% a.i. release compared with 2 days of exposure to 10 mm rainfall). **Based on a.i., release studies it is estimated that release of hexazinone from PRONONE 10G granules would be within 1-2 weeks in northern Alberta when applied during the label-specified time of application.**

Environmental distribution, movement, and persistence of hexazinone were examined in the main study site in the Grande Prairie area, using the granular formulation PRONONE 10G, for 1) hexazinone leaching in soil free-water, 2) lateral movement of hexazinone residues in the permanent and ephemeral streams, 3) persistence and mobility of hexazinone in soils, 4) horizontal and vertical variation of hexazinone residues in soils, and 5) uptake and dissipation of hexazinone residues in vegetation.

Small amounts of hexazinone residues were found reaching a 80-cm depth at the μg level in soil leachate. The rate of hexazinone movement in soil leachate increased with the rate of soil water percolation but declined over time. There were 5 ppb to nondetectable amounts of hexazinone residues found in the ephemeral stream flowing around the treatment plots, but no residues were detected in six surface-water and bottom-sediment collection sites along Campbell Creek, a permanent stream and the collector of surface runoff from the experimental areas. **Amounts of hexazinone residues found in soil leachate as well as in surface water and sediment in pools near the application site were small and were 50,000 to 1,000,000 times lower than the reported LC_{50} for fish and wildlife and are unlikely to pose any detrimental effect to the environment.** Residues of hexazinone and its two major metabolites A and B in soils were analyzed up to 767 days after treatment. Residues leached to soil depths of 10-20, 20-30, 30-35, and 35-40 within 8, 37, 37, and 365 days respectively in both 2 and 4 kg/ha hexazinone treatments. DT_{50} (dissipation time required for

residues to reduce to 50% of amounts applied) of hexazinone in soil were 12 and 27 days, respectively, for 0-10 cm and the combined total (0-40 cm) layers in 2 kg ai/ha treatment and 13 and 29 days, respectively, in 4 kg ai/ha treatment. The presence of metabolites was in accordance with their parent compound at relatively low level, and indicated the continuous breakdown of hexazinone over time in the deeper, perhaps near-anaerobic, soils. Results of this study were further confirmed in a separate study, where hexazinone residues were not quantifiable in soils between 40 and 210 cm depth. Although the coefficient of variation (CV) of both the horizontal and vertical distribution of hexazinone in soils varied between 30 and 150%, the total amounts of residues were reduced to 16 and 4% of the amount applied, respectively, 1 and 2 years after treatment. **Due to the environmental concerns, it is recommended jointly by Forestry Canada, Alberta Environment, and the Alberta Forest Service that soil samplings be continued until the residues of hexazinone are reduced to nondetectable levels in two consecutive samplings.**

The foliage of several species accumulated hexazinone and its metabolites. The maximum accumulations were detected in May to July of the first growing season following the fall application. By the end of second growing season, most of the plant species did not show any hexazinone residues. Maximum intake of hexazinone by animals feeding on foliage and twigs of aspen and Calamagrostis can be expected between 40 and 2300 μg/kg of the dry matter consumed. These concentrations are much below the acute toxicity levels for various animals. The animals feeding on herbicide-impacted vegetation are expected to consume small amounts of hexazinone, mostly during the first year following application and negligibly in the second growing season and none thereafter. The small mammal study carried out by Penner and Associates Ltd. (Penner 1990) did find extremely low concentrations of hexazinone in liver and kidney of small mammals during the 1st year. No, or extremely low, quantities of hexazinone are expected to be consumed by wildlife feeding on the winter twigs of woody species. The level of accumulation in twigs was 0.56-7.7% of that in the foliage of willow, aspen, and honeysuckle. Under normal conditions, over 90% of the hexazinone consumed by animals is likely to be excreted within 72 hours. Based on the hexazinone and its metabolite concentrations detected in several species of plants detected over 2 years of monitoring, residues detected in small mammals, and acute toxicity data for hexazinone and its metabolites, **it can be concluded that 1) hexazinone and its metabolites do accumulate and dissipate in vegetation and small mammals, 2) most accumulation occurs during the 1st year after application, and 3) detected concentrations are much below the acute toxicity levels in various organisms**.

The study of the **effects of hexazinone and other herbicides on mycorrhizae** by in vitro tests concluded that mycorrhizae fungal growth was reduced in culture media at concentrations of 10 or greater ppm of hexazinone. Hexazinone at 2 and 4 kg/ha affected the seedling growth and mycorrhizal infections negatively over a period of greater than 6 months in the greenhouse. Phytotoxic and fungitoxic effects of the herbicide were less intense under field conditions. The herbicide application did not result in the mortality of the mycorrhizal inoculum in the soil, and seedlings planted in herbicide-treated plots in the field formed well-developed mycorrhizae within 2 months after planting. Phytotoxic effects of hexazinone were greater in crop seedlings with mycorrhizae than in those without mycorrhizal infections. Based on the reported effects of hexazinone on microorganisms and results of the present study on mycorrhizae, **it is concluded that hexazinone at 1 and 2 kg/ha would have no or very little effect on mycorrhizal development in white spruce and lodgepole pine under field conditions**. However, there was an insignificant reduction in mycorrhizal development at 4 kg/ha rate. Based on the results of field and greenhouse studies, **no long-term negative effect of hexazinone is expected on the survival of mycorrhizal inoculum and development of mycorrhizal infections in white spruce and lodgepole pine at 1-4 kg/ha rates under field conditions**.

The effect of hexazinone application resulted in alterations in the nutrient status in foliage and nutrient balance in soil at least during the two years following the herbicide application. The fall application of hexazinone resulted in a general increase of K, P, S, and total N, increases being more pronounced in the 4 kg/ha than in the 2 kg/ha rate. Normal seasonal dynamics of Ca and Mg in foliage was disrupted. **The intensity of the effects declined by the end of second growing season (1988) and by 1989 (third growing season) there were no significant differences in the nutrient status of foliage from control and herbicide-treated plots.** Gross changes in nutrient status in foliage are also reflected in alterations of nutrient dynamics in soils for up to 2 years. As it is difficult to extrapolate changes that occurred over 2 years to long-term future productivity, **it is recommended that soil dynamics studies be carried out at 3-5 and 8- year intervals following the herbicide application.**

ACKNOWLEDGMENTS

We acknowledge our major collaborators in both field and laboratory studies: C. Feng and S. Navratil (Northern Forestry Centre), G. Ehrentraut and J. Drew (Alberta Forest Service), V. Stornes and R. Rogers (Pro-Serve Inc.), and V. Servant (Alberta Environment); and the technical assistance of J. Hudson, M. Macklen, L. Milward, C. Dunn, K. Richardson, N. Haidar, M. Osgood, and J. Lane for hexazinone chemistry and residue analysis. The technical assistance of M. Fairbarns in vegetation sampling, computer aids, and data analysis was significant in completing the vegetation section of the study and the report. Our thanks are due to Dr. D. Maynard for contributing the Section 8.2 to the report. Most of all, the cooperation of L. Brace in coordinating different components of the FRDA project is greatly appreciated. We appreciate the patience of Joyce Simunkovic for typing this long manuscript. Finally, the study could not have been undertaken without the Canada-Alberta FRDA funding.

REFERENCES

Baron, J.J.; Monaco, T.J. 1986. Uptake, translocation and metabolism of hexazinone in blueberry (*Vaccinium* sp.) and hollow golden rod (*Solidago fistulosa*). Weed Sci. 34:824-829.

Barring, U.; Torstensson, L. 1983. An example of the mobility of hexazinone on a slope. Swedish Weed Conf. 24:311-325.

Beste, C.E., editor. 1983. Herbicide handbook. 5th ed. Weed Sci. Soc. Am., Urbana, Ill.

Bostack, H.S. 1970. Physiographic subdivisions of Canada. Pages 10-30 *in* R.J.W. Douglas, ed. Geology and economic minerals of Canada. Dep. Energy, Mines and Resources. Geological Survey of Canada. Econ. Geol. Rep. 1. 838 pp + maps.

Bouchard, D.C.; Lavy, T.L.; Lawson, E.R. 1985. Hexazinone adsorption-desorption studies with soil and organic adsorbents. J. Environ. Qual. 14:181-186.

Boyd, R.; Miller, D.; Kidd, F.; Ritter, C. 1985. USDA For. Serv., Intermt. Res. Stn. Res. Note INT-195.

Bremner, J.M.; Mulvaney, C.S. 1982. Nitrogen - Total. Pages 595-624 *in* A.L. Page, R.H. Miller, and D.R. Keeney, editors. Methods of soil analysis, Part 2. Agronomy No. 9, Am. Soc. Agron., Madison, Wis.

Burstein, H. 1971. Attribute sampling: tables and explanations. McGraw-Hill, New York. 464 pp.

Cantrel, R. 1985. A guide to silviculture herbicide use in the southern United States Auburn Univ., School of For., Alabama Agric. Exp. Stn., Auburn, Ala.

Chakravarty, P.; Sidhu, S.S. 1987a. Effect of glyphosate, hexazinone and triclopyr on *in vitro* growth of five species of ectomycorrhizal fungi. Eur. J. For. Pathol. 17:204-210.

Chakravarty, P.; Sidhu, S.S. 1987b. Effect of hexazinone (Pronone 5G) on the seedling growth and mycorrhizal incidence of *Pinus contorta* var. *latifolia* and *Picea glauca*. Eur. J. For. Pathol. 17:282-291.

Chapin, F.S.; Johnson, F.S.; McKendrick, J.D. 1980. Seasonal movement of nutrients in plants of differing growth form in an Alaskan tundra ecosystem: Implications for herbivory. J. Ecol. 68:189-209.

Corns, I.G.W.; Annas, R.M. 1986. Field guide to forest ecosystems of west-central Alberta. Can. For. Serv., North. For. Cent., Edmonton, Alta.

Dimock, E.J., II; Beebe, T.F.; Collard, E.B. 1983. Planting-site preparation with herbicides to aid conifer restoration. Weed Sci. 31:215-221.

Feng, J.C. 1987. Persistence, mobility and degradation of hexazinone in forest silt loam soils. J. Environ. Sci. Health (Part B) 22:221-233.

Feng, J.C. 1988. Cross-wind effect on aerial application of granular hexazinone. Expert Comm. Weeds West. Can. Sect. 1988 Res. Rep. 3:203.

Feng, J.C. 1989. Granular herbicide application by helicopter equipped with a bucket spreader. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:212.

Feng, J.C.; Campbell, R.A. 1985. New methods for soil sampling and residue reporting in a study on persistence of Velpar L in boreal forest soils. Expert Comm. Weeds East. Can. Sect. 1985 Res. Rep. P. 593.

Feng, J.C.; Ehrentraut, G.B.; Drew, T.J. 1989. Deposition of hexazinone from a logarithmic sprayer. J. Environ. Sci. Health (Part B) 24:525-537.

Feng, J.C.; Feng, C.C. 1988a. Persistence of hexazinone in Alberta soils. Expert Comm. Weeds West. Can. Sect. 1988 Res. Rep. 3:182.

Feng, J.C.; Feng, C.C. 1988b. Determination of hexazinone residues and their fate in a New Brunswick forest. Can. For. Serv. Inf. Rep. FPM-X-81.

Feng, J.C.; Feng, C.C. 1989. Persistence of hexazinone two years after application in silty clay soil. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:191.

Feng, J.C.; Feng, C.C.; Sidhu, S.S. 1989. Determination of hexazinone residues and its release from a granular formulation under forest conditions. Can. J. For. Res. 19:378-381.

Feng, J.C.; Klassen, H.D. 1986. Forestry field and laboratory manual for herbicide residue sampling, sample processing and reporting. Can. For. Serv. Inf. Rep. FPM-X-72.

Feng, J.C.; Navratil, S. 1989. Evaluation of a new soil sampling method for herbicide residues immediately after spraying. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:192.

Feng, J.C.; Navratil, S. 1990. Sampling for zero-time hexazinone residues in forest soils for dissipation study. Can. J. For. Res. 20:1549-1552.

Feng, J.C.; Sidhu, S.S. 1989. Distribution of blank hexazinone granules from aerial and ground applicators. Weed Technol. 3:275-281.

Feng, J.C.; Sidhu, S.S.; Feng, C.C. 1989a. Persistence and leachability of hexazinone in deep soils. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:193.

Feng, J.C.; Sidhu, S.S.; Feng, C.C. 1989b. Performance of a commercial granular applicator in hexazinone application. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:211.

Feng, J.C.; Sidhu, S.S.; Feng, C.C.; Servant, V. 1989. Hexazinone residues and dissipation in soil leachates. J. Environ. Sci. Health (Part B) 24:131-143.

Feng, J.C.; StonesS, V.; Rogers, R. 1988. Release of hexazinone from PRONONE 10G granules exposed to simulated rainfall under laboratory conditions. J. Environ. Sci. Health (Part B) 23:267-278.

Feng, J.C.; Thompson, D.G. 1989. Persistence and dissipation of glyphosate in foliage and soils of a Canadian coastal forest watershed. Pages 65-87 in P. Reynolds, editor. Proceedings of Carnation Creek Herbicide Workshop, Nanaimo, B.C., December 1987. For. Can., Pest Manage. Inst., Sault Ste. Marie, Ont.

Freeman, F.W.; White, D.P.; Bukovac, M.J. 1964. Uptake and differential distribution of C14-labelled simazine in red and white pine seedlings. For. Sci. 10:330-334.

Freese, F. 1962. Elementary forest sampling. USDA For. Serv., Agric. Handb. 232:24-28.

Ghassemi, M.; Fargo, L.; Painter, P.; Quinlivan, S.; Scofeild, R.; Tailata, A. 1981. Environmental fates and impacts of major forest use pesticides. TRW, Redondo Beach, Calif.

Ghassemi, M.; Quinlivan, S.; Dellario, M. 1982. Environmental effects of new herbicides for vegetation control in forest. Environ. Int. 7:389-401.

Grigal, D.F.; Ohmann, L.F.; Brander, R.B. 1976. Seasonal dynamics of tall shrubs in northeastern Minnesota: biomass and nutrient element changes. For. Sci. 22:195-208.

Harrington, K.C.; Rolston, M.P.; Ivens, G.W. 1982. Movement of hexazinone spots applied to hill slopes. Pages 162-165 in Proceedings of the 35th N.Z. Weed and Pest Control Conf.

Hatzios, K.K.; Howe, C.M. 1982. Influence of herbicides hexazinone and chlorsulfuron on the metabolism of isolated soybean leaf cells. Pestic. Biochem. Physiol. 17:207-214.

Hill, M.O. 1979. DECORANA: a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Section of Ecology and Systematics. Cornell Univ., Ithaca, N.Y. 52 pp.

Holmgreen, G.G.S.; Juve, R.L.; Geschwender, R.C. 1977. A mechanically controlled variable rate leaching device. Soil Sci. Soc. Am. J. 41:1207-1209.

Holt, R.F. 1981. Determination of hexazinone and metabolite residues using nitrogen-selective gas chromatography. J. Agric. Food Chem. 29:165-172.

Hurlbert, S.M. 1971. The non-concept of species diversity: a critique and alternative parameters. Ecology 52:577-586.

Kalra, Y.P.; Maynard, D.G.; Radford, F.G. 1989. Microwave digestion of tree foliage for multi-element analysis. Can. J. For. Res. 19:981-985.

Kimmins, J.P. 1987. Effect of herbicidal reduction of early successional vegetation on the biochemistry of a small low elevation watershed in coastal British Columbia. Final report of PRUF contract O1SE-5-0020; OSE85-00068, Univ. British Columbia.

Krause, H.H. 1982. Nitrate formation before and after clearcutting of a monitored watershed in central New Brunswick, Canada. Can. J. For. Res. 12:922-930.

Kuhnke, D.H. 1989. Silviculture statistics for Canada: an 11 year summary. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-301.

Lavy, T.L.; Mattice, J.D.; Kochenderfer, J.N. 1989. Hexazinone persistence and mobility of a steep forested watershed. J. Environ. Qual. 18:507-514.

Likens, G.E.; Bormann, F.H.; Johnson, N.M.; Fisher, D.W.; Pierce, R.S. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. Ecol. Monogr. 40:23-47.

Lowery, R.F. 1984. Hexazinone-sintered clay for hardwood control. *In* Proc. South. Weed Sci. Soc. 37:237-241.

Malik, N.; Vamdem Born, W.H. 1986. Use of herbicides in forest management. Can. For. Serv. Inf. Rep. NOR-X-282.

Mayack, D.T.; Bush, P.B.; Neary, D.G.; Douglass, J.E. 1982. Impact of hexazinone on invertebrates after application to forested watersheds. Arch. Environ. Contam. Toxicol. 11:209-217.

Maynard, D.G.; Kalra, Y.P.; Radford, F.G. 1987. Extraction and determination of sulfur in organic horizons of forest soils. Soil Sci. Soc. Am. J. 51:801-806.

McColl, J.G. 1980. Seasonal nutrient variation in trembling aspen. Plant & Soil 54:323-328.

McNeil, W.K.; Stritzke, J.F.; Basler, E. 1984. Absorption, translocation and degradation of tebuthiuron and hexazinone in woody species. Weed Sci. 32:739-743.

McQuaker, N.R.; Brown, D.F.; Kluckner, P.D. 1979. Digestion of environmental materials for anlaysis by inductively coupled plasma-atomic emission spectrometry. Anal. Chem. 51:1082-1084.

Miller, J.H.; Bace, A.C. 1980. Streamwater contamination after aerial application of a pelletized herbicide. USDA For. Serv., South. For. Exp. Stn. Res. Note SO-225.

Mueller-Dombois, D.; Ellenberg, H. 1974. Aims and methods of vegetation ecology. John Wiley, New York. 547 pp.

Navratil, S.; Lane, J. 1987. Control of aspen development in areas designated for softwood production: summary of satellite trials A, B, C. Pages 4-19 in Canada-Alberta Forest Resource Development Agreement Rep., Alta. For. Serv. For. Res. Branch, Spruce Grove, Alta.

Neary, D.G. 1983. Monitoring herbicide residues in springflow after an operational application of hexazinone. South. J. Appl. For. 7:217-223.

Neary, D.G. 1988. Effect of pesticide applications on forested watersheds. Pages 325-337 in W.T. Swank and D.A. Crossly, Jr., eds. Forest hydrology and ecology at Coweeta. Ecological Studies 66. Springer-Verlag, New York.

Neary, D.G.; Bush, P.B.; Douglass, J.E. 1983. Off-site movement of hexazinone in stormflow and baseflow from forest watersheds. Weed Sci. 31:543-551.

Neary, D.G.; Bush, P.B.; Grant, M.A. 1986. Water quality of ephemeral forest streams after site preparation with the herbicide hexazinone. For. Ecol. Manage. 14:23-40.

Olsen, S.R.; Sommers, L.E. 1982. Phosphorus. *In* A.L. Page, ed. Methods of soil analysis, Part 2. 2nd ed. Agronomy 9:403-430.

Payne, N.; Feng, J.; Reynolds, P. 1987. Off-target deposit measurements and buffers required around water for aerial glyphosate application. Can. For. Serv. Inf. Rep. FPM-X-80.

Penner, D. 1990. Small mammals in hexazinone treated clearcut in mixedwood boreal forests in north-central Alberta: a final report. Penner and Assoc., Sherwood Park, Alta.

Prasad, R.; Feng, J.C. 1990. Spotgun applied hexazinone: release of red pine (*Pinus resinosa*) from aspen (*Populus tremuloides*) competition and residue persistence in soil. Weed Technol. 4:371-375.

Reiser, R.W.; Belasco, I.R.; Rhodes, R.C. 1983. Identification of metabolites of hexazinone by mass spectrometry. Biomed. Mass Spectrom. 10:581-585.

Rhodes, R.C. 1980a. Soil studies with ^{14}C-labelled hexazinone. J. Agric. Food Chem. 28:311-315.

Rhodes, R.C. 1980b. Studies with ^{14}C-labelled hexazinone in water and bluegill sunfish. J. Agric. Food Chem. 28:306-310.

Rhodes, R.C.; Jewell, R.A. 1980. Metabolism of ^{14}C-labelled hexazinone in the rat. J. Agric. Food Chem. 28:303-306.

Rhodes, R.C.; Krause, R.L.; Williams, M.H. 1980. Microbial activity in soils treated with hexazinone. Soil Sci. 129:311-314.

Robertson, G.P.; Vitousek, P.M.; Matson, P.A.; Tiedje, J.M. 1987. Denitrification in a clearcut loblolly pine (*Pinus taeda* L.) plantation in the southeast U.S. Plant & Soil 97:119-127.

Rowe, J.S. 1972. Forest Regions of Canada. Can. For. Serv., Publ. 1300. 172 pp.

Roy, D.N.; Konar, S.K.; Banerjee, S.; Charles, D.A.; Thompson, D.G.; Prasad, R. 1989. Persistence, movement, and degradation of glyphosate in selected Canadian boreal forest soils. J. Agric. Food Chem. 37:437-440.

Roy, D.N.; Konar, S.K.; Charles, D.A.; Feng, J.C.; Prasad, R.; Campbell, R.A. 1989. Determination of persistence, movement, and degradation of hexazinone in selected Canadian boreal forest soils. J. Agric. Food Chem. 37:443-447.

Sidhu, S.S.; Chakravarty, P. 1990. Effect of selected forestry herbicides on ectomycorrhizal development and seedling growth of lodgepole pine and white spruce under controlled and field environment. Eur. J. For. Pathol. 20(2):77-94.

Sidhu, S.S.; Feng, J.C.; Feng, C.C. 1989. Persistence and levels of hexazinone residues in some plant species. Expert Comm. Weeds West. Can. Sect. 1989 Res. Rep. 3:221.

Sikka, H.C.; Davis, D.E. 1968. Absorption, translocation and metabolism of prometryne in cotton and soybean. Weed Sci. 16:474-477.

Steel, R.G.D.; Torrie, J.H. 1960. Principles and procedures of statistics. McGraw-Hill, New York.

Sung, S.S.; South, D.B.; Gjerstad, D.H. 1985. Bioassay indicates a metabolite of hexazinone affects photosynthesis of loblolly pine (*Pinus taeda*). Weed Sci. 33:440-442.

Tappeiner, J.C.; Alm, A.A. 1975. Undergrowth vegetation effects on the nutrient content of litterfall and soils in red pine and birch stands in northeastern Minnesota. Ecology 56:1193-1200.

Tecator. 1985. Kjaltec auto 1030 analyzer manual. Tecator, AB. Hoganas, Sweden.

Technicon Instrument Corporation. 1971. Nitate + nitrite in water. Industrial method No. 32-69W. Technion Instrument Corp., Tarrytown, New York.

Technicon Instrument Corporation. 1973. Ammonia in water and seawater. Industrial method No. 154-71W, Technicon Instrument Corporation, Tarrytown, New York.

Thompson, D.G.; Stephenson, G.R.; Solomon, K.R.; Skepasts, A.V. 1984. Persistence of (2,4-dichlorophenoxy)acetic acid and 2-(2,4-dichlorophenoxy)propionic acid in agricultural and forest soils of northern and southern Ontario. J. Agric. Food Chem. 32:578-581.

Tilton, D.L. 1977. Seasonal growth and foliar nutrients of *Larix laricina* in three wetland ecosystems. Can. J. Bot. 55:1291-1298.

Twardy, A.G.; Dowgray, A.I.T. 1985. Soil survey of two cutblocks test areas and detailed analysis of blocks within the test area. Report prepared by Pedology Consultants for Canada-Alberta FRDA Project, Edmonton, Alta. 96 pp.

Votousek, P.M.; Matson, P.A. 1985. Disturbance, nitrogen availability, and nitrogen losses in an intensively managed loblolly pine plantation. Ecology 66:1360-1376.

Vitousek, P.M.; Melillo, J.M. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. For. Sci. 25:605-619.

Weidenfeller, T. A. 1985. Granular herbicides in lake states forestry. In Proc. North Cent. Weed Control Conf. 40:31-32.

William, R.; Burrel, L.; Parker, R.; Swan, G.; Howard, S.; Kidder, D. 1987. Pacific Northwest Weed Control Handbook. Ext. Serv., Oregon State Univ., Washington State Univ., and Univ. of Idaho.

WSSA (Weed Science Society of America). 1983. Herbicide handbook. 5th ed. Weed Sci. Soc. Am., Champaign, Ill.

Yates, W.E.; Cowden, R.E.; and Akesson, N.B. 1985. Atomization of herbicide simulants with hollow cone and raindrop nozzles. USDA For. Serv., For. Pest Manage. FPM 85-1.

Zar, J.H. 1980. Biostatistical analysis. 2nd ed. Prentice-Hall, Englewood Cliffs, N.J. 718 pp.

APPENDIX A

PLANT SPECIES PRESENT IN TREATMENT PLOTS GRANDE PRAIRIE VEGETATION MANAGEMENT PROJECT 1985-89

Achillaea millefolium L.	Common yarrow
Actaea rubra (Ait.) Willd.	Baneberry
Agropyron trachycaulum (Link) Malte	Slender wheat grass
Agrostis scabra Willd.	Hair grass
Alnus crispa (Ait.) Pursh	Green alder
A. tenuifolia Nutt.	River alder
Amelanchier alnifolia Nutt.	Saskatoon-berry
Antennaria neglecta Greene	Pussy-toes
Apocynum and *rosaeimifolium* L.	Spreading dogbane
Arabis hirsuta (L.) Scop.	
A. holboellii Hornem.	Rock-cress
Aralia nudicaulis L.	Sarsaparilla
Arctostaphylos uva-ursi (L.) Spreng.	Common bearberry
Arenaria lateriflora L.	Grove sandwort
Arnica cordifolia Hook.	Heartleaf arnica
Aster ciliolatus Lindl.	Lindley's aster
A. conspicuus Lindl.	Showy aster
Beckmannia syzigachne (Steud.) Fern.	Slough grass
Betula glandulosa Michx.	Scrub birch
B. papyrifera Marsh.	White birch
Bromus ciliatus L.	Fringed brome
B. inermis Leyss.	Awnless brome
Calamagrostis canadensis (Michx.) Nutt.	Marsh reed grass
Carex brunnescens (Pers.) Poir.	Sedge
C. disperma Dewey	Sedge
C. macloviana d'Urv.	Sedge
C. praticola Rydb.	Sedge
Castilleja miniata Dougl.	Red paint-brush
Cerastium arvense L.	Chickweed
Chenopodium album L.	Lamb's-quarter
Chrysanthemum leucanthemum L.	Ox-eye Daisy
Cornus canadensis L.	Bunchberry
C. stolonifera Michx.	Red osier dogwood
Corydalis aurea Willd.	Golden corydalis
Corylus cornuta Marsh.	Beaked hazelnut
Crepis tectorum L.	Annual hawksbeard
Cystopteris fragilis (L.) Bernh.	Bladder fern
Disporum trachycarpum (S. Watts.) B.& H.	Fairy bells
Elymus glaucus± Buckl.	Smooth wild rye
E. innovatus Beal	Hairy wild rye
Epilobium angustifolium L.	Fireweed
E. glandulosum Lehm.	Willow-herb
Equisetum arvense L.	Field horsetail
E. sylvaticum L.	Wood horsetail
Festuca rubra L.	Red fescue

Fragaria virginiana Duchesne	Wild strawberry
Galeopsis tetrahit L.	Hemp nettle
Galium boreale L.	Northern bedstraw
G. triflorum Michx.	Sweet-scented bedstraw
Gentianella amarella (L.) Börner	Felwort
Geranium bicknellii Britt.	Crane's bill
Geum allepicum Jacq.	Yellow avens
G. macrophyllum Willd.	Yellow avens
Halenia deflexa (Sm.) Griseb.	Spurred gentian
Heracleum lanatum Michx.	Cow parsnip
Hieracium umbellatum L.	Narrow-leaved hawkweed
Juncus balticus Willd.	Wire rush
Lathyrus ochroleucus Hook.	White pea vine
Linnaea borealis L.	Twinflower
Lonicera dioica L.	Twining honeysuckle
L. involucrata (Richards.) Banks	Bracted honeysuckle
Lycopudium annotinum L.	Stiff club-moss
L. elavatum L.	Running club-moss
Maianthemum canadense Web.	Mayflower
Mertensia paniculata (Ait.) G. Don.	Lungwort
Mitella nuda L.	Bishop's cap
Oryzopsis asperifolia Michx.	Rice grass
Petasites palmatus (Ait.) A. Gray	Palmate-leaved coltsfoot
P. sagittatus (Pursh) A. Gray	Arrow-leaved coltsfoot
Phleum pratense L.	Common timothy
Picea glauca (Moench) Voss	White spruce
P. mariana (Mill.) BSP.	Black spruce
Pinus contorta Dougl. var. *latifolia* Engelm.	Lodgepole pine
Poa palustris L.	Fowl bluegrass
P. pratense L.	Kentucky bluegrass
Populus balsamifera L.	Balsam poplar
P. tremuloides Michx.	Trembling aspen
Potentilla norvegica L.	Rough cinquefoil
Prunus pensylvanica L.f.	Pin cherry
P. virginiana L.	Choke cherry
Pyrola asarifolia Michx.	Common pink wintergreen
P. secunda L.	One-sided wintergreen
Ranunculus abortivus L.	Small-flowered crowfoot
Ribes lecustre (Pers.) Poir.	Prickly currant
R. oxyacanthoides L.	Wild gooseberry
R. triste Pall.	Wild red currant
Rosa acicularis Lindl.	Wild rose
Rubus pubescens Raf.	Running raspberry
R. strigosus Michx.	Wild red raspberry
Salix spp.	Willow
Sanicula marilandice L.	Snake-root
Schizachne pupurascens (Torr.) Swallen	False Melic
Senecio pauperculus Michx.	Groundsel, ragwort
Shepherdia canadensis (L.) Nutt.	Canadian buffalo-berry
Smilacina racemosa (L.) Desf.	False Solomon's seal

S. stellata (L.) Desf.	Star-flowered Solomon's seal
Solidago canadensis L.	Canada goldenrod
Spiraea betulifolia Dougl.	Meadowsweet
Stellaria longifolia Muhl. ex Willd.	Long-leaved chickweed
Symphoricarpos albus (L.) Blake	Snowberry
Taraxacum officinale Weber	Dandelion
Thalictrum venulosum Trel.	Veiny meadow rue
Trifolium repens L.	White clover
Vaccinium caespitosum Michx.	Dwarf bilberry
V. myrtilloides Michx.	Blueberry
V. vitis-idaea L.	Cowberry
Viburnum edule (Michx.) Raf.	Lowbush cranberry
Vicia americana Muhl.	Blue vetch
Viola adunca J.E. Smith	Early blue violet
V. renifolia A. Gray	Kidney-leaved violet
V. rugulosa Greene	Western Canada violet

APPENDIX B

PERCENT FREQUENCY IN COVER CLASSES (1986-1989) IN CONTROL AND HEXAZINONE-TREATED PLOTS

Figure 1. For *Aralia nudicaulis*

Figure 2. For *Aster ciliolatus*

Figure 3. For *Aster conspicuus*

Figure 4. For *Calamagrostis canadensis*

Figure 5. For *Cornus canadensis*

Figure 6. For *Epilobium angustifolium*

Figure 7. For *Fragaria Virginiana*

Figure 8. For *Galium boreale*

Figure 9. For *Lathyrus ochroleucus*

Figure 10. For *Populus tremuloides* (>150 cm)

Figure 11. For *Populus tremuloides* (50-150 cm)

Figure 12. For *Populus tremuloides* (< 50 cm)

Figure 13. For *Rosa acicularis*

Figure 14. For *Spiraea betulifolia*

Figure 15. For *Viburnum edule*

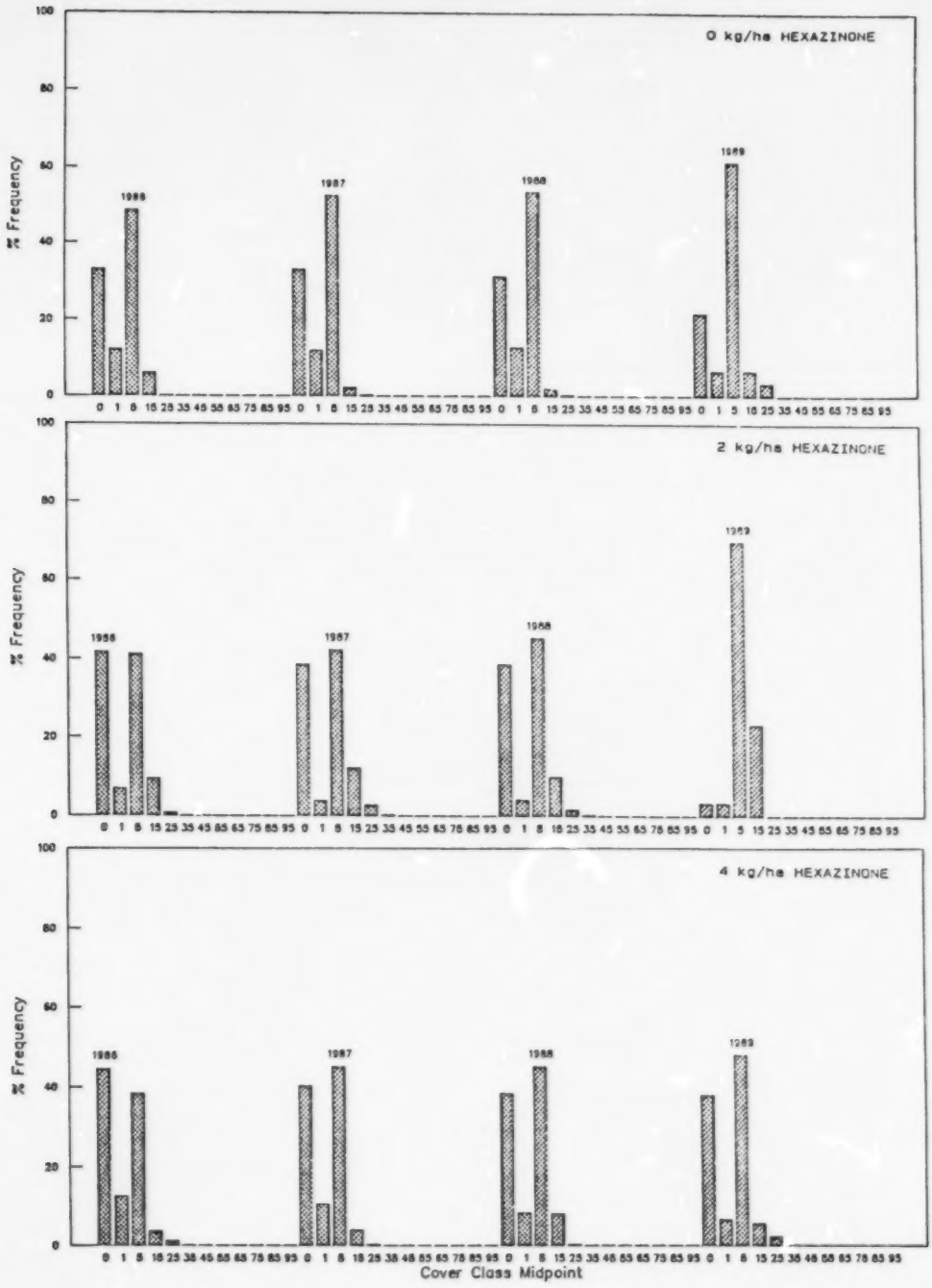

Figure 1 Percent frequency of cover classes (1986-1989) for *Aralia nudicaulis* in control and hexazinone-treated plots.

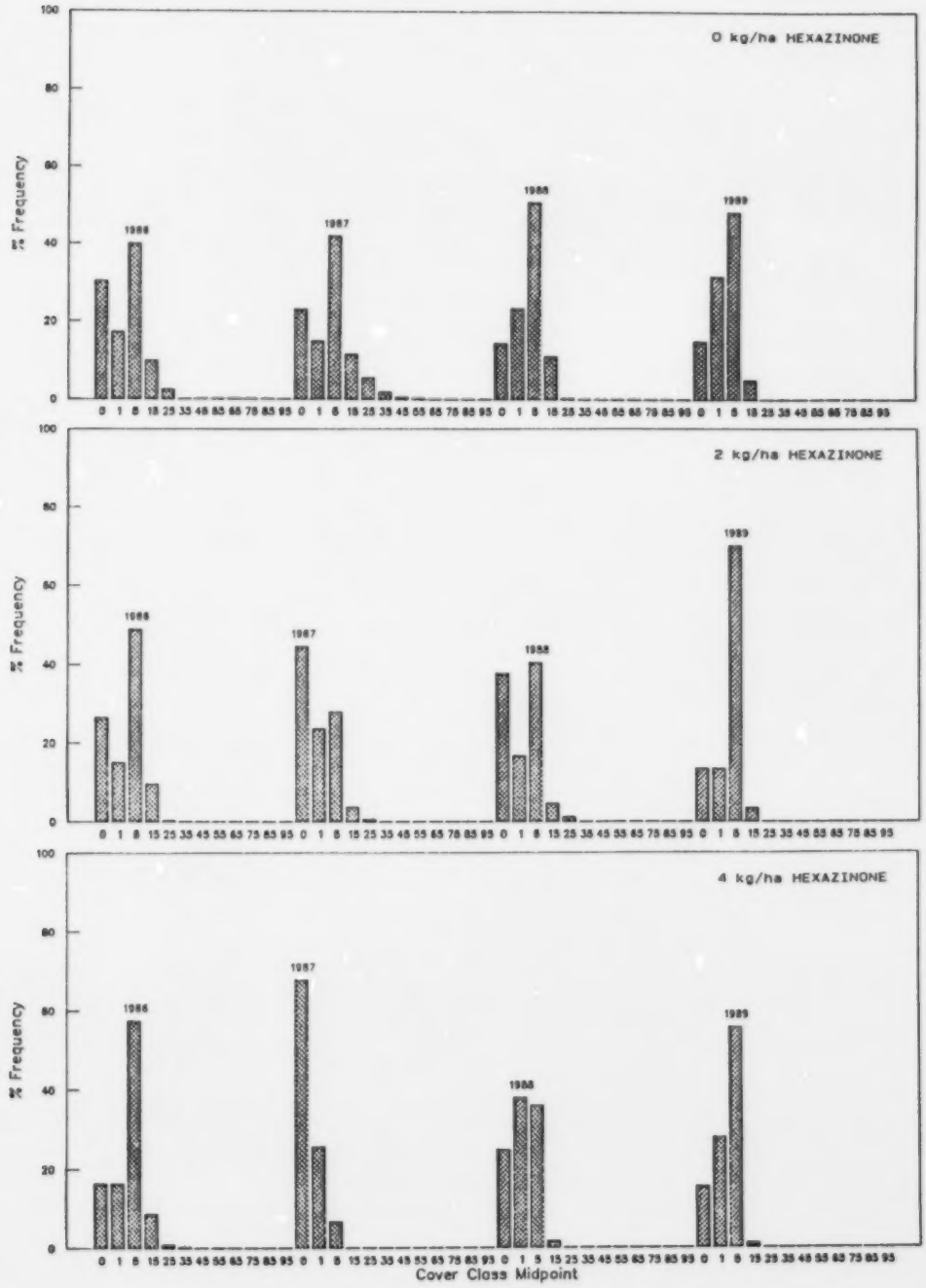

Figure 2. Percent frequency of cover classes (1986-1989) for *Aster ciliolatus* in control and hexazinone-treated plots.

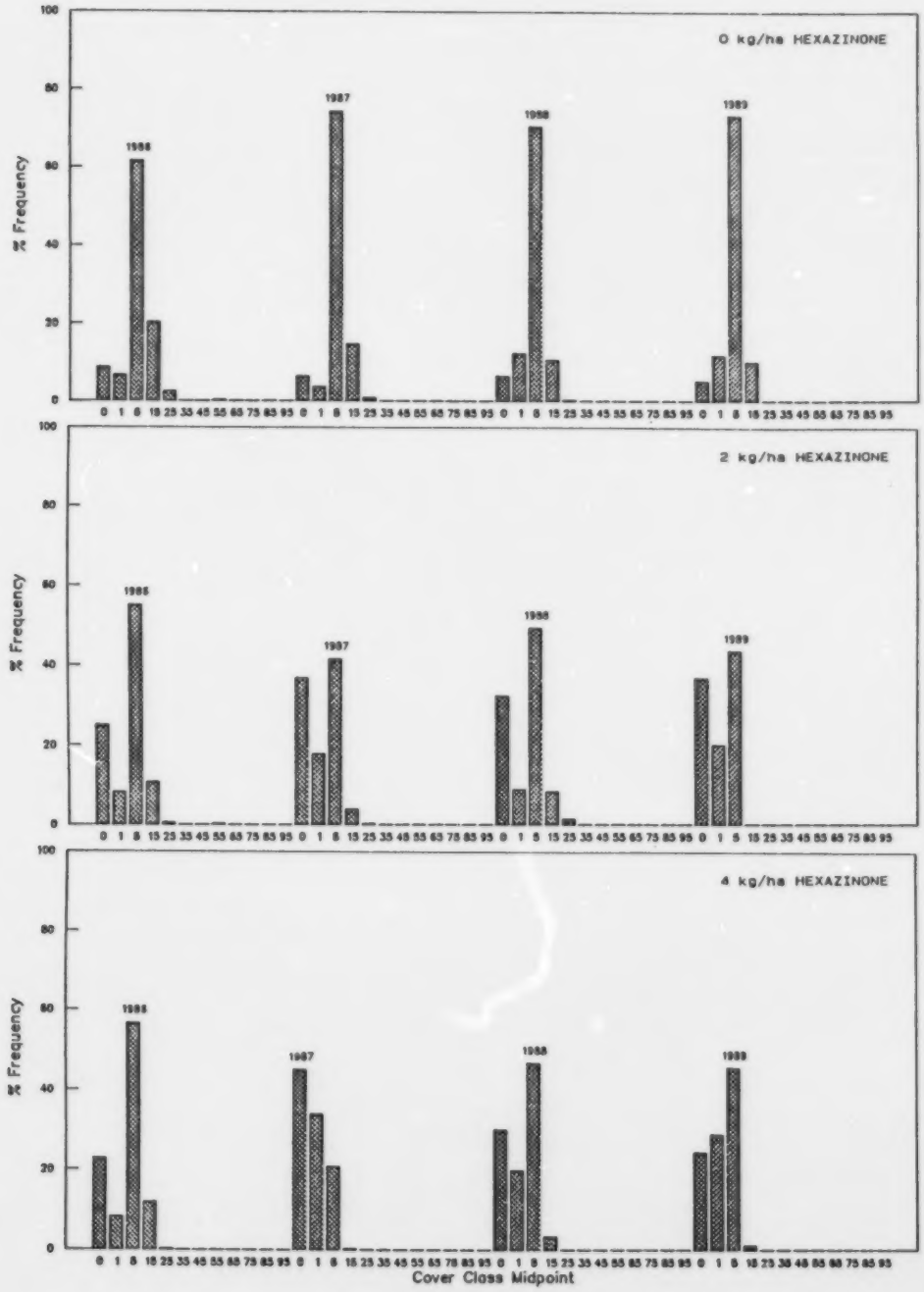

Figure 3. Percent frequency of cover classes (1986-1989) for *Aster conspicuus* in control and hexazinone-treated plots.

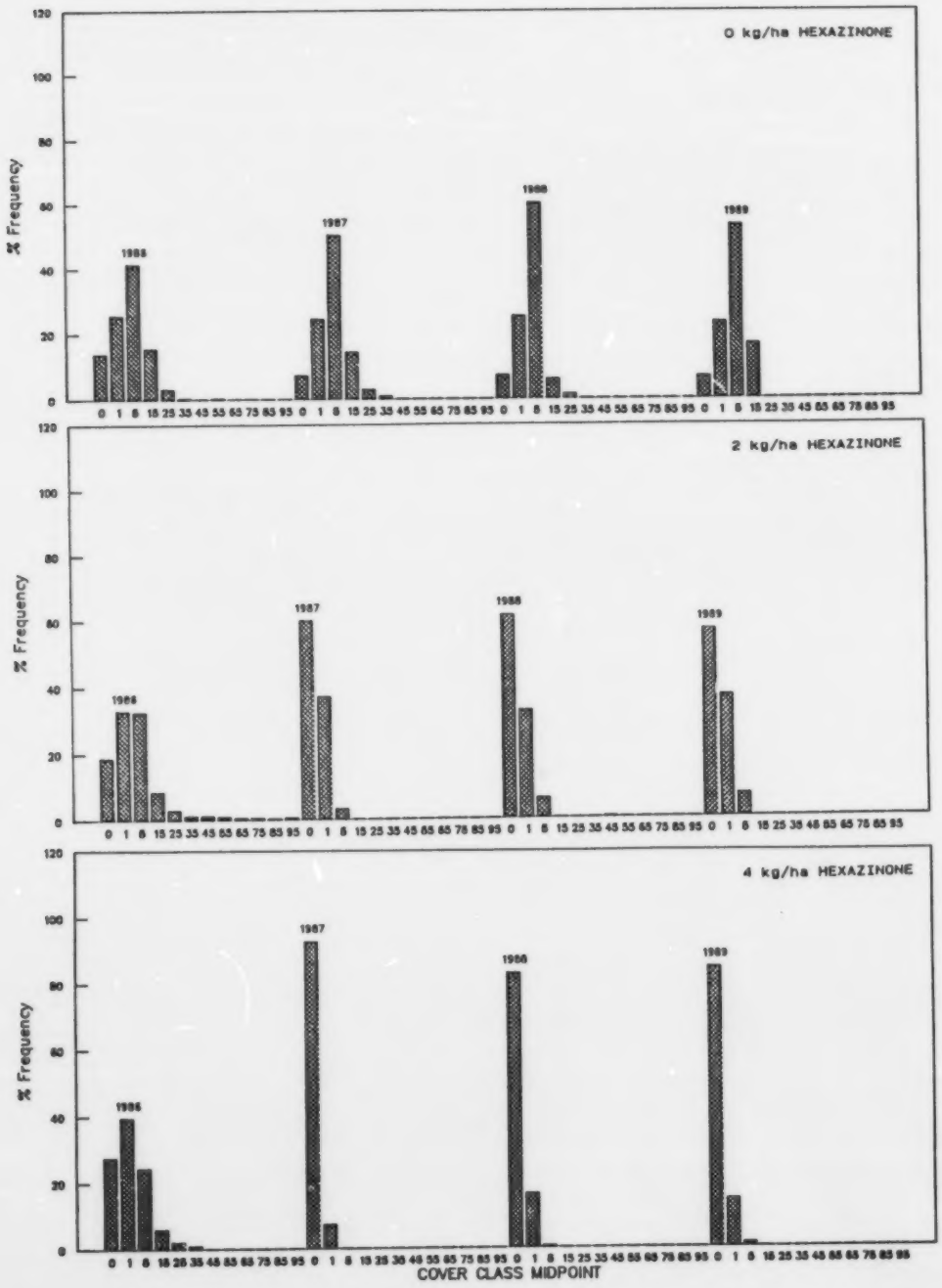

Figure 4. Percent frequency of cover classes (1986-1989) for *Calamagrostis canadensis* in control and hexazinone-treated plots.

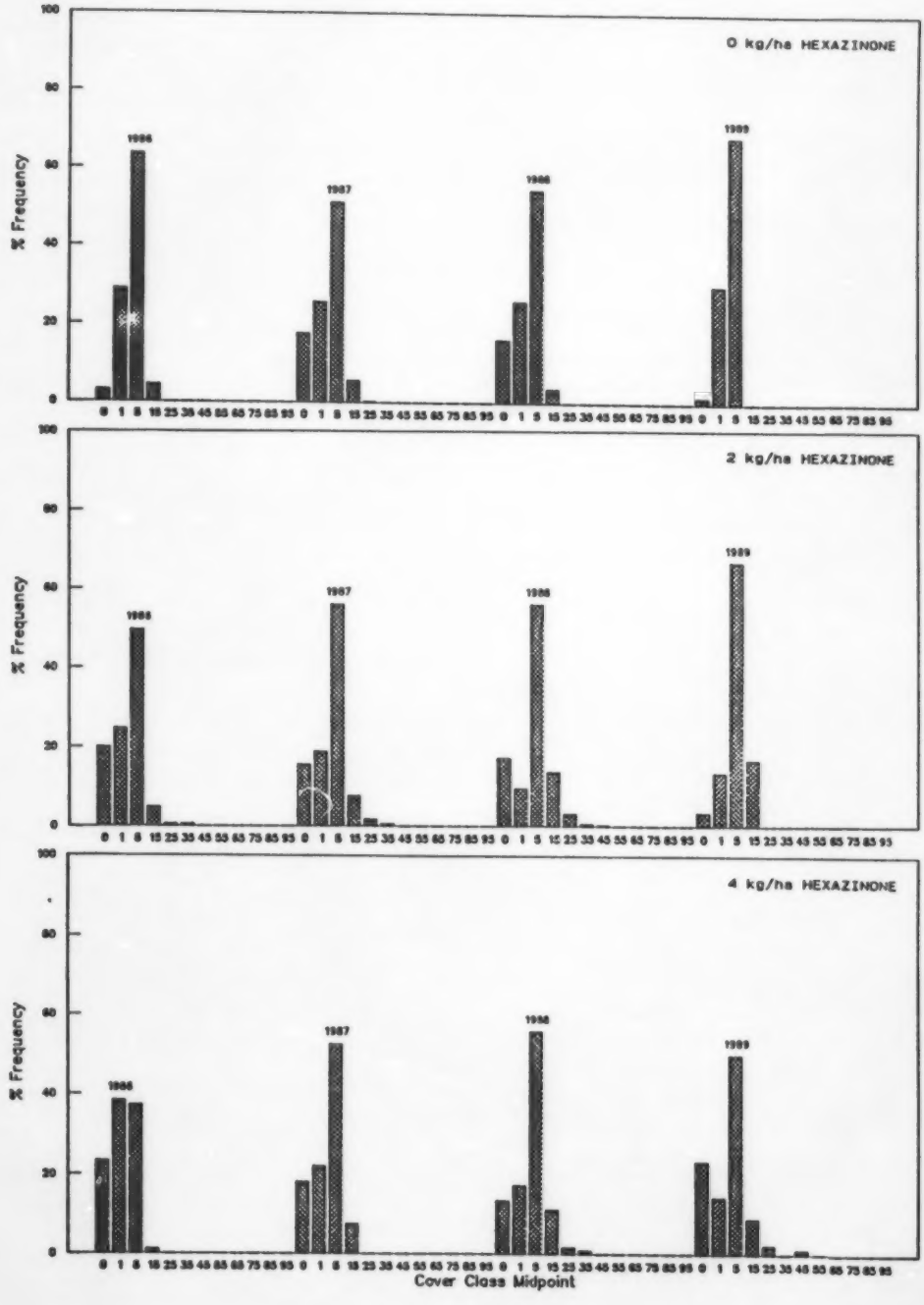

Figure 5. Percent frequency of cover classes (1986-1989) for *Cornus canadensis* in control and hexazinone-treated plots.

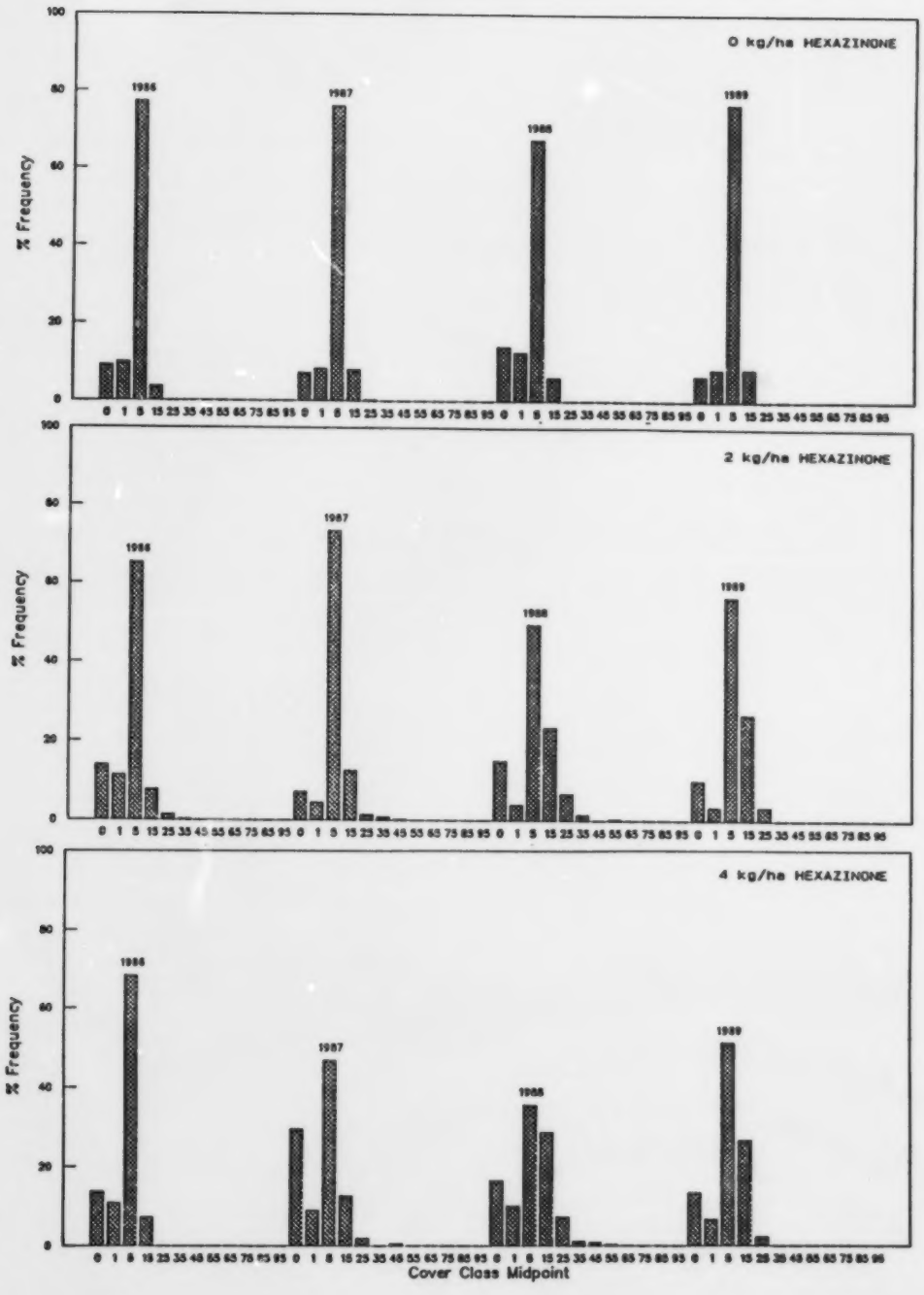

Figure 6. Percent frequency of cover classes (1986-1989) for *Epilobium angustifolium* in control and hexazinone-treated plots.

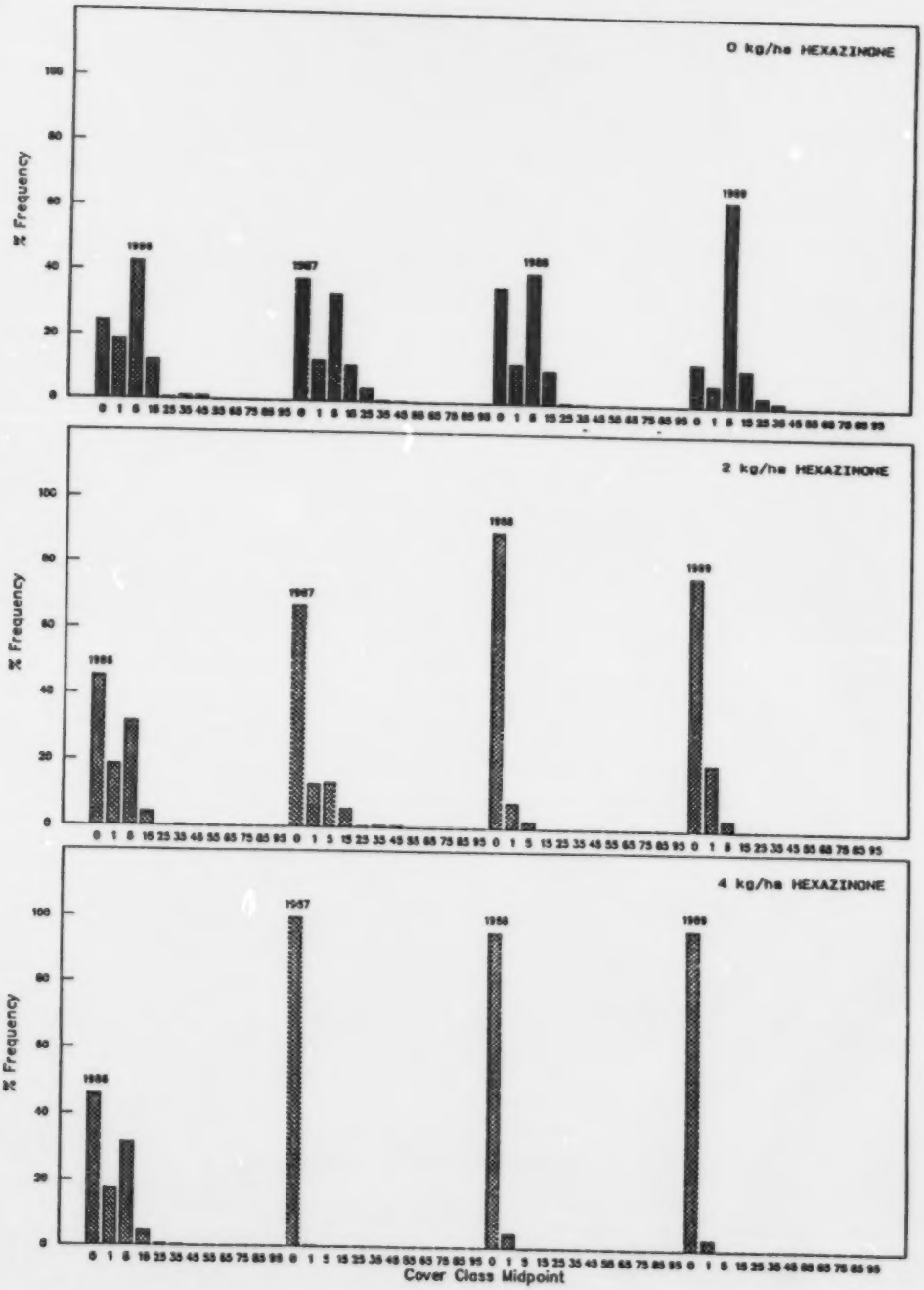

Figure 7. Percent frequency of cover classes (1986-1989) for *Fragaria virginiana* in control and hexazinone-treated plots.

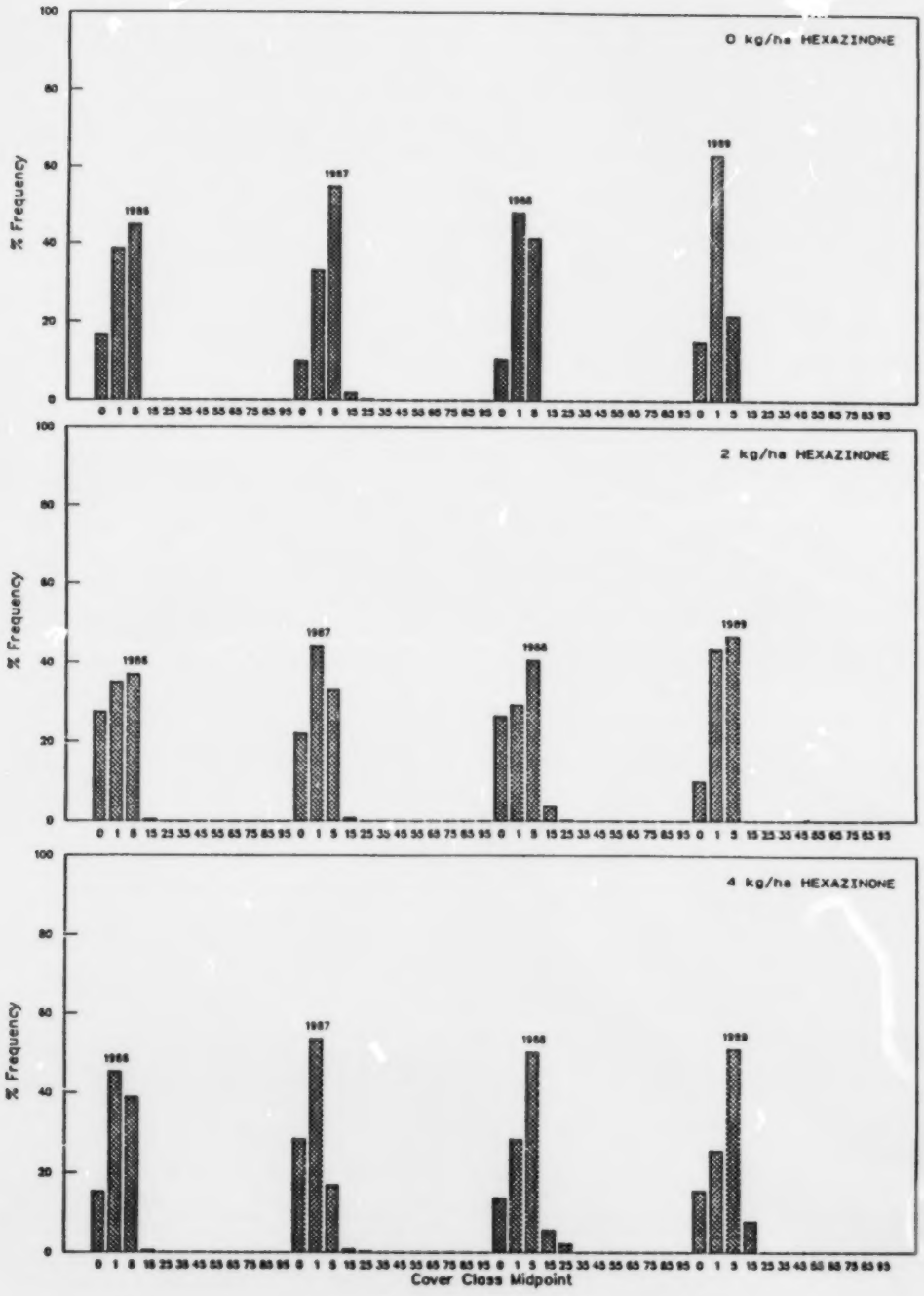

Figure 8. Percent frequency of cover classes (1986-1989) for *Galium boreale* in control and hexazinone-treated plots.

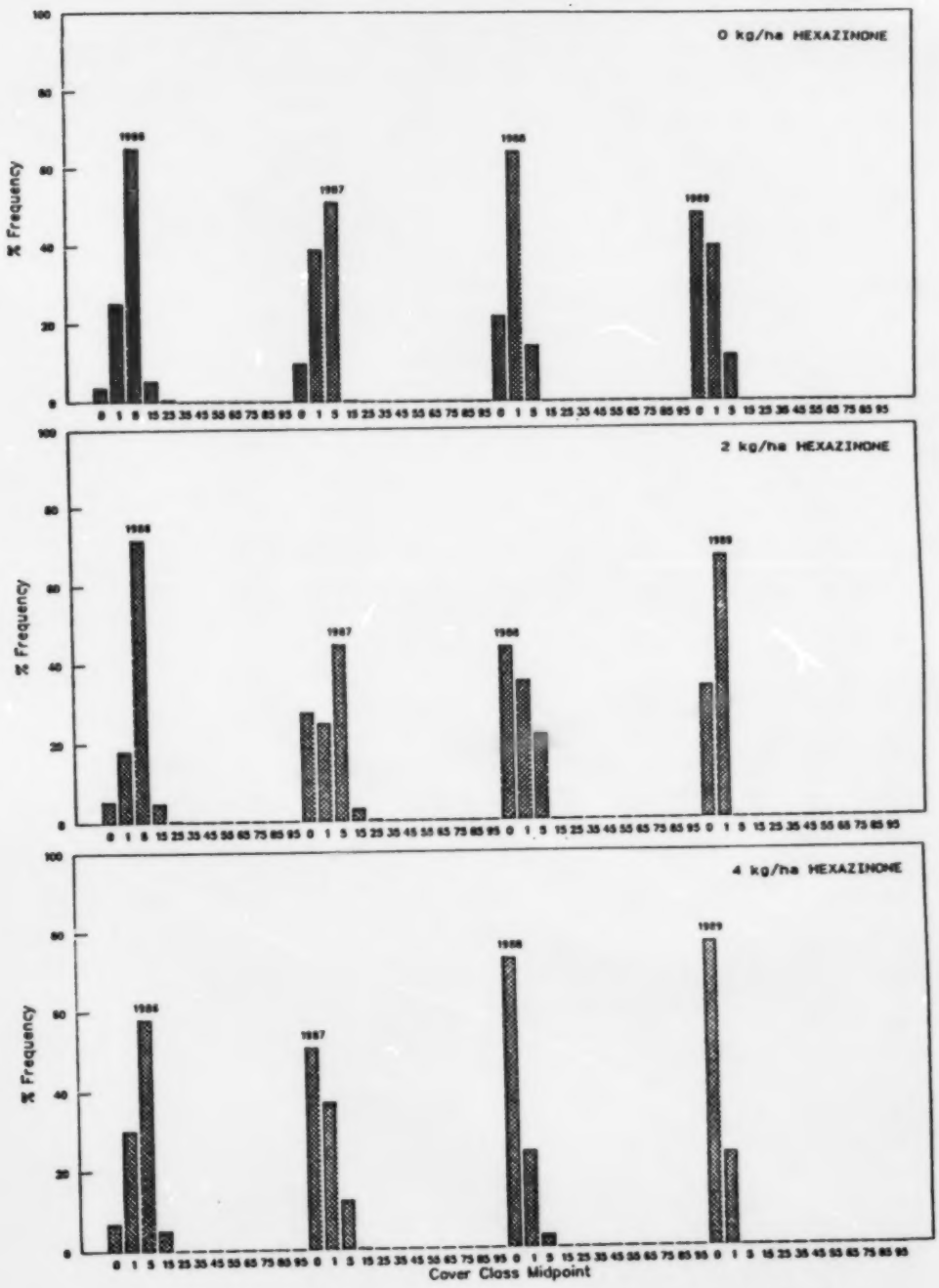

Figure 9. Percent frequency of cover classes (1986-1989) for *Lathyrus ochroleucus* in control and hexazinone-treated plots.

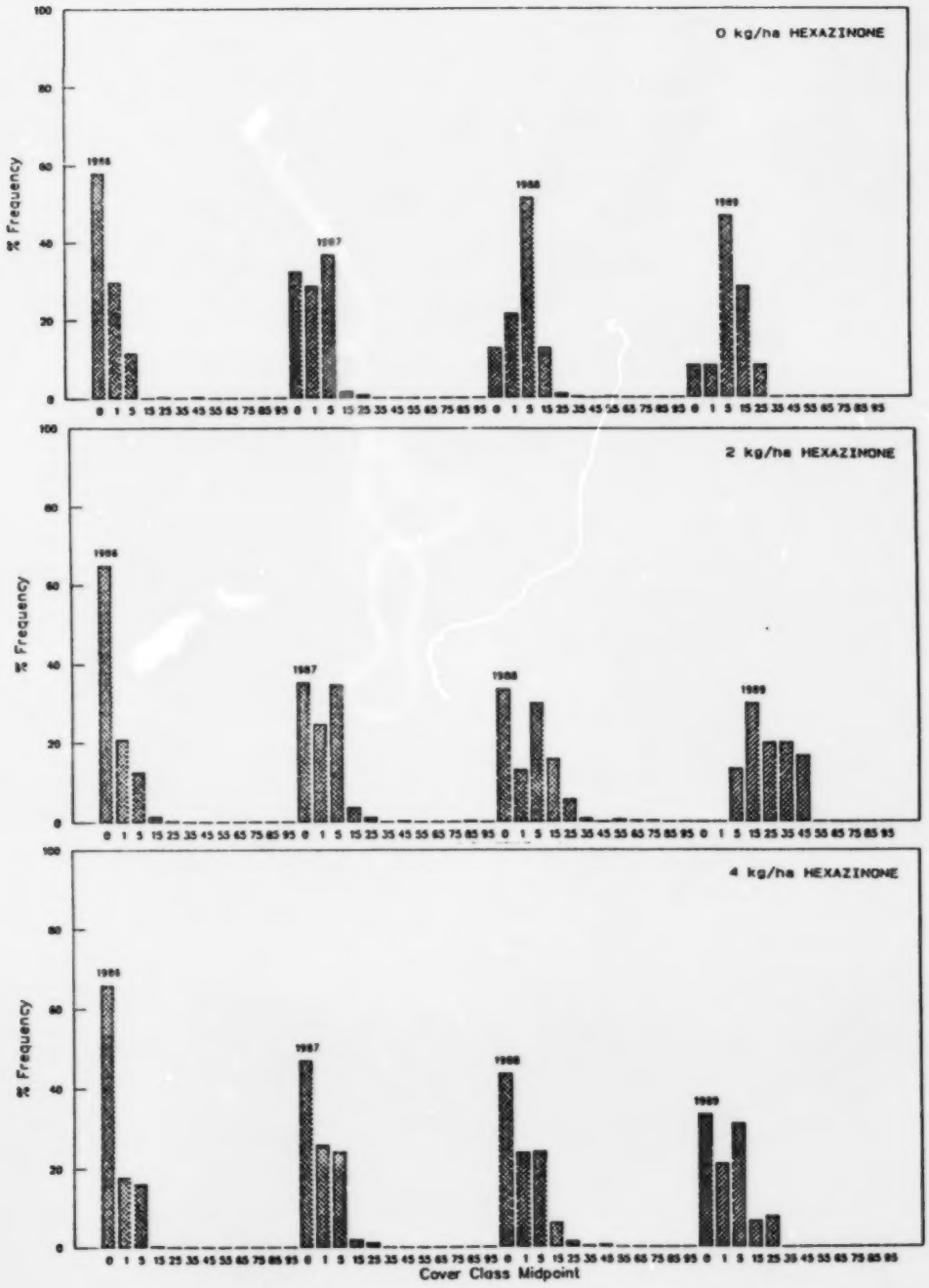

Figure 10. Percent frequency of cover classes (1986-1989) for *Populus tremuloides* (>150 cm) in control and hexazinone-treated plots.

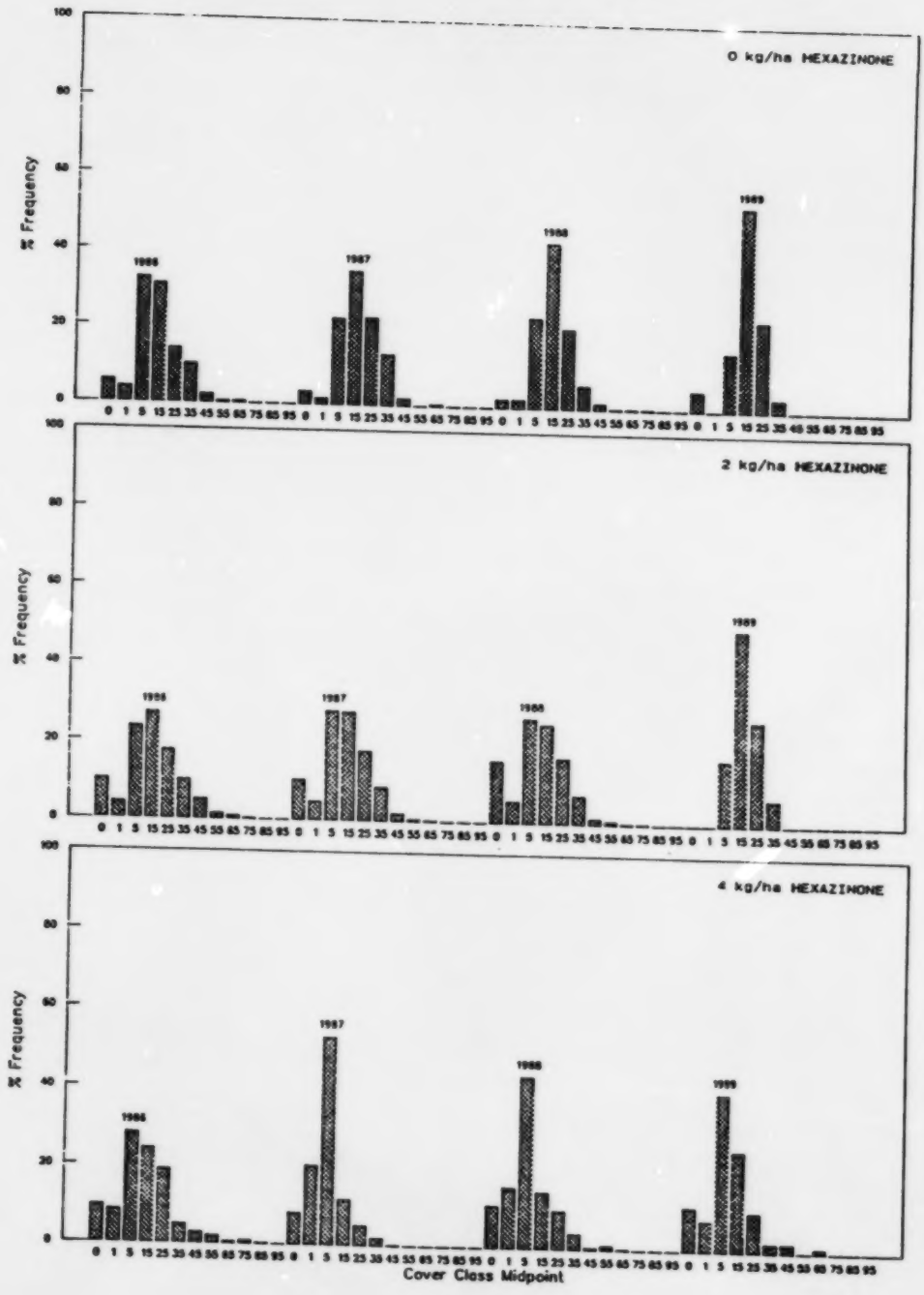

Figure 11. Percent frequency of cover classes (1986-1989) for *Populus tremuloides* (50-150 cm) in control and hexazinone-treated plots.

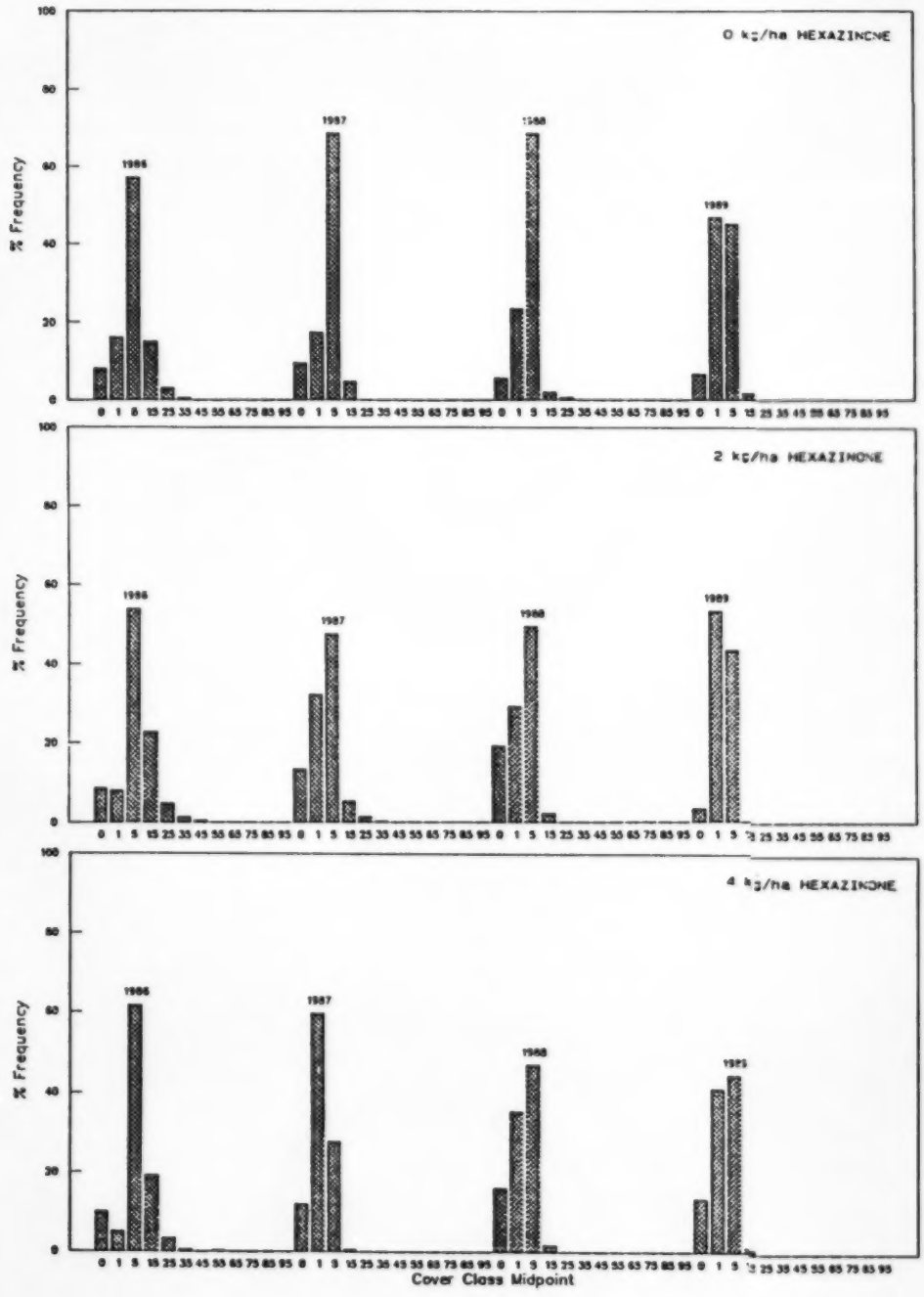

Figure 12. Percent frequency of cover classes (1986-1989) for *Populus tremuloides* (< 50 cm) in control and hexazinone-treated plots.

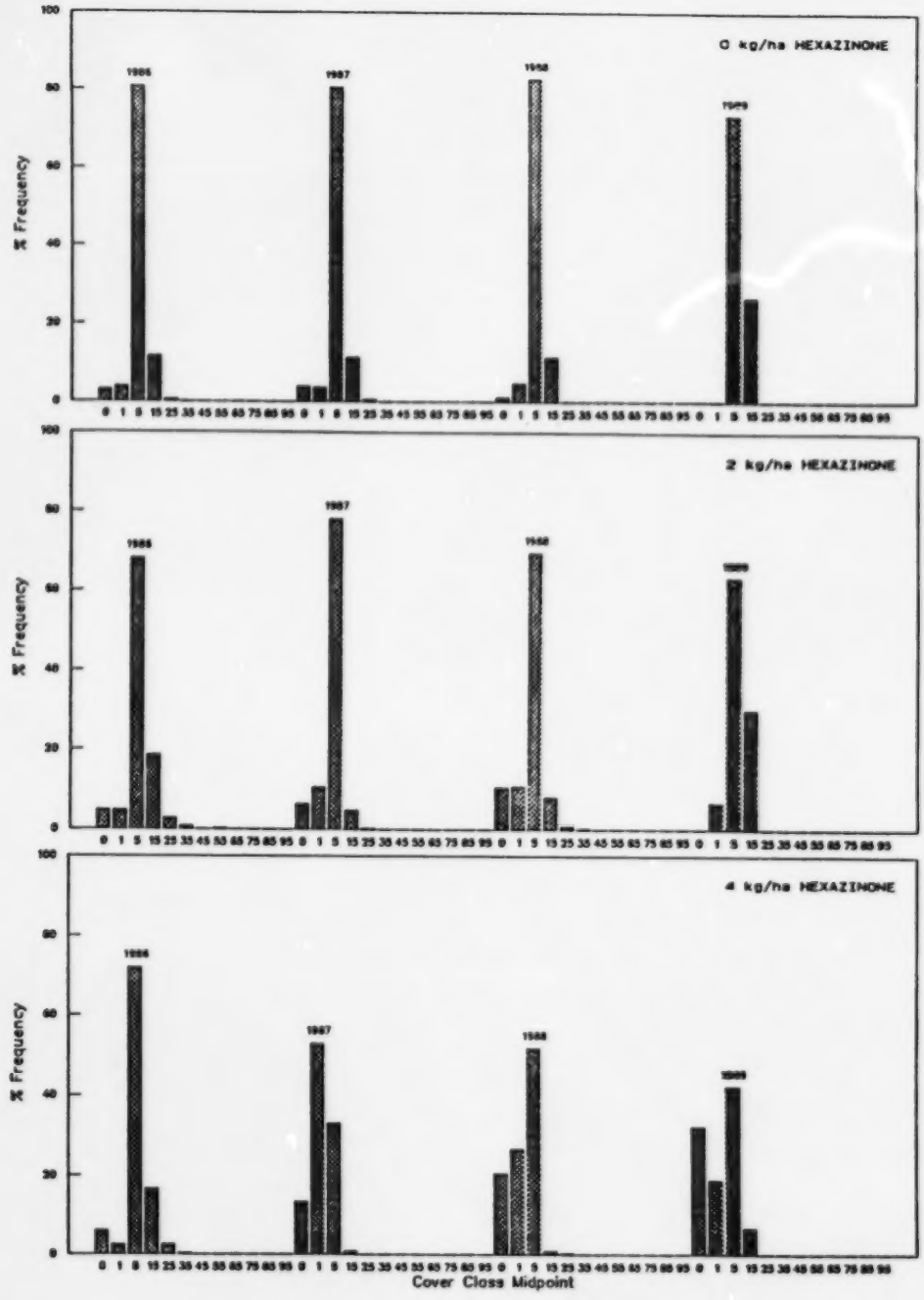

Figure 13. Percent frequency of cover classes (1986-1989) for *Rosa acicularis* in control and hexazinone-treated plots.

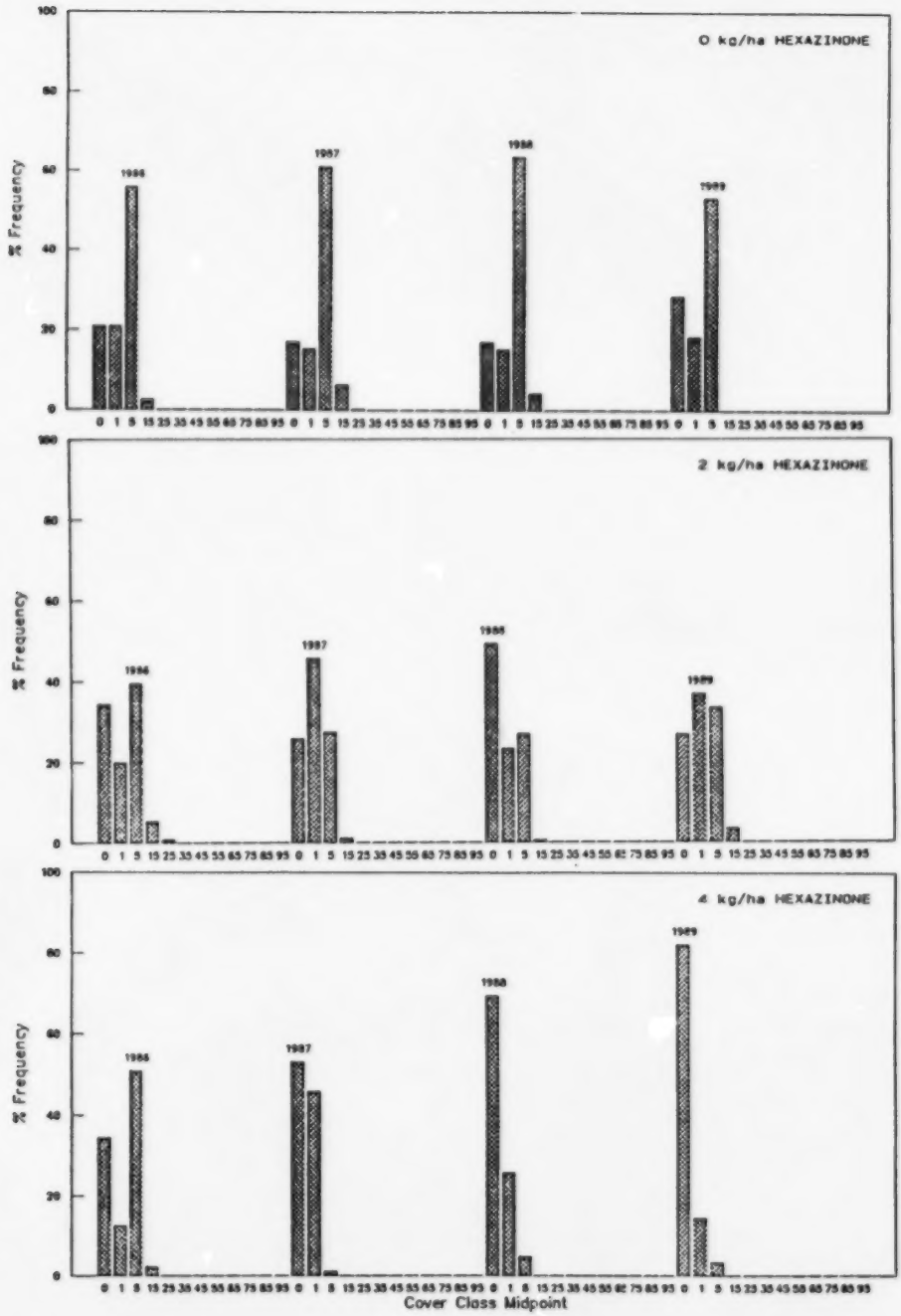

Figure 14. Percent frequency of cover classes (1986-1989) for *Spiraea betulifolia* in control and hexazinone-treated plots.

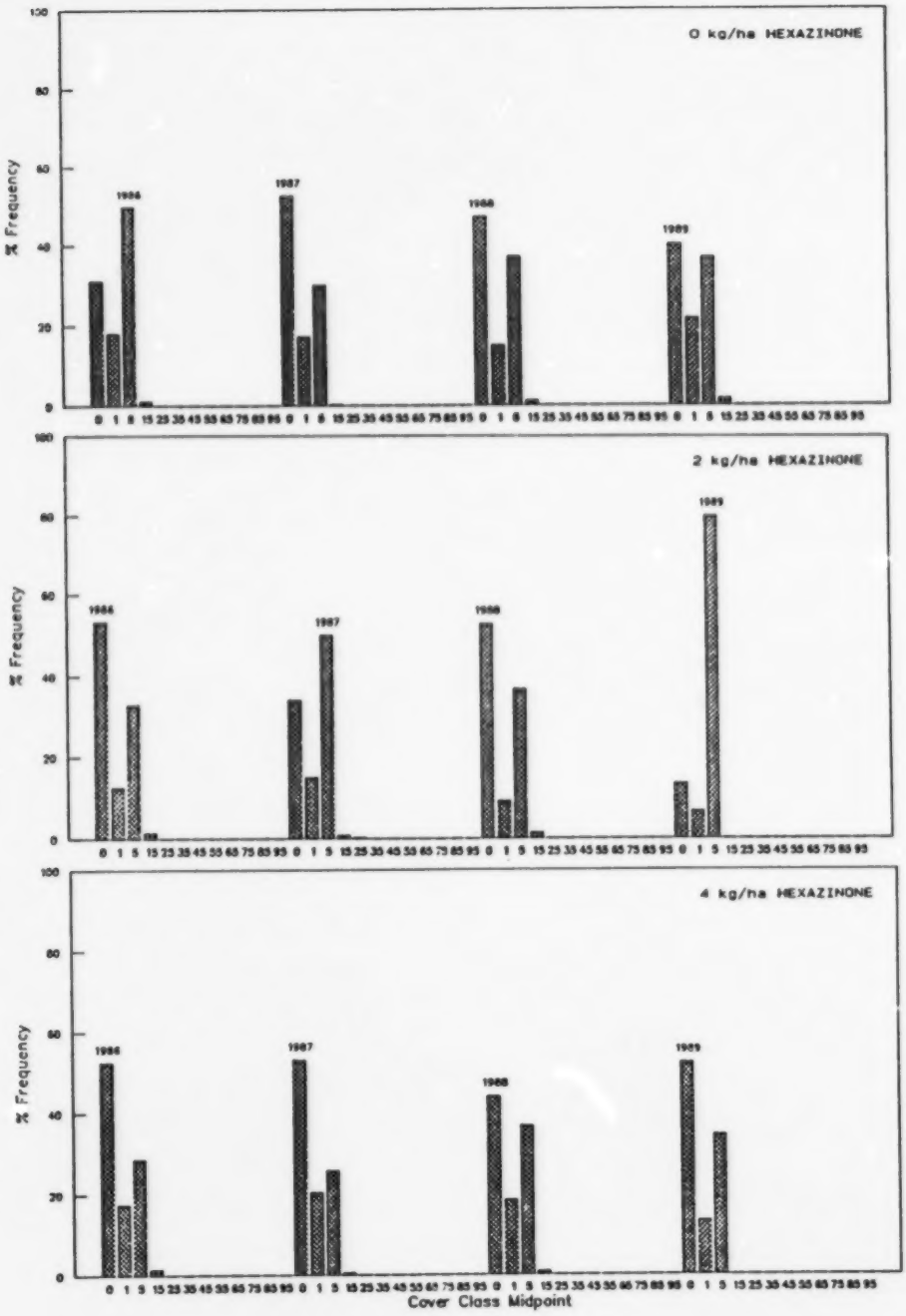

Figure 15. Percent frequency of cover classes (1986-1989) for *Viburnum edule* in control and hexazinone-treated plots.

APPENDIX C

Table 8-1

Nutrient analysis of foliage and twigs of selected species from Pronone-treated and control plots of the Grande Prairie study, in mg/kg (except total N) of material and blank subtracted

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
Aster conspicuus foliage											
27 MAY 1987:[a]											
HH-Plot[b]	Average	10820	4130	29.2	66550	280	34.0	84.2	8320	2975	6.10
	±S	±680	±206	±20.1	±3790	±80	±28.9	±23.9	±1240	±240	±0.43
LH-Plot	Average	7800	3098	5.70	53000	197	15.0	157	5900	2257	5.22
	±S	±160	±28	±3.70	±950	±32	±16.4	±133	±745	±38	±0.06
C-Plot	Average	7610	2760	93.0	48735	165	71.2	28.3	5770	2185	4.84
	±S	±870	±260	±62.5	±2845	±48	±48.3	±33.3	±840	±220	±0.29
24 JUNE 1987:											
HH-Plot		13725	5705	64.0	65077	233	155	291	7656	3020	5.71
LH-Plot		7433	3812	< 3.53	52569	142	142	255	5736	2460	4.48
C-Plot		7631	3436	< 3.53	47621	71.6	6.29	41.6	3619	1357	3.02
15 JULY 1987:											
HH-Plot		10821	3899	< 3.53	56702	119	< 5.56	60.6	4249	1724	3.61
LH-Plot		9333	3150	<3.530	48256	141	50.5	214	3383	1309	3.28
C-Plot	Average	10070	2900	<3.53	36670	110	30.5	64.5	2640	830	1.80
	±S	±1660	±87.8	-	±6790	±18.7	±19.3	±55.0	±985	±335	±0.90
2 SEPTEMBER 1987:											
HH-Plot		10446	3777	86.9	47580	240	< 5.560	28.0	5042	2178	5.00
LH-Plot		10616	3548	<3.53	32102	137	< 5.560	53.0	2748	1050	1.99
C-Plot		14249	3676	<3.530	23205	221	35.4	< 0.34	1531	567	1.10
2 AUGUST 1988:											
HH-Plot		12404	3844	33.0	47281	156	54.9	92.9	2834	1239	1.92
LH-Plot		15889	3790	12.6	47265	193	34.3	75.1	2961	1017	1.55
C -Plot		16263	4475	10.9	43697	217	34.9	54.6	2892	956	1.48

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
12 JULY 1989:											
HH-Plot	Average	12511	3821	113	36682	116	217	92.9	3824	1193	2.07
	±S	±1362	±481	±13.0	±1377	±76.7	±18.7	±12.7	±603	±138	±0.41
LH-Plot	Average	11293	3809	81.4	40011	142	127	86.6	4004	1276	1.93
	±S	1501	±307	±70.1	±1593	±23.9	±65.5	±17.0	±875	±283	±0.30
C-Plot	Average	12752	3598	78.8	43457	201	153	126	3814	1172	1.99
	±S	±2450	±397	±67.6	±5135	±49.7	±55.4	±90.4	±625	±117	±0.14
Aster conspicuus stem											
24 JUNE 1987:											
HH-Plot		3692	1838	< 3.53	26588	48.9	< 5.56	3.06	1655	644	1.71
LH-Plot		3382	1572	< 3.53	24531	52.7	< 5.56	15.5	1432	439	1.52
C-Plot		5992	1806	< 3.53	33586	77.7	< 5.56	9.73	2066	628	1.22
15 JULY 1987:											
HH-Plot		5485	2577	< 3.53	21500	80.2	< 5.56	13.4	2218	762	1.31
LH-Plot		5723	2798	<3.53	22955	67.9	< 5.56	19.2	1979	655	1.55
C-Plot		9307	2882	< 3.53	24768	90.2	23.8	41.0	2044	554	0.99
Populus tremuloides foliage											
27 MAY 1987:											
HH-Plot	Average	8076	3895	48.9	19895	81.1	75.8	69.9	6822	2821	5.89
(100% DEAD foiage)	±S	±2985	±611	±40.9	±5069	±5.78	±46.5	±32.2	±999	±324	±0.48
LH-Plot	Average	8963	4415	< 3.53	25792	115	< 5.56	126	7336	3491	8.48
	±S	6254	3167	18.8	15790	69.6	24.8	67.1	4564	2110	4.83
C-Plot	Average	±887	±365	±26.4	±2906	±5.5	±26.6	±31.5	±1192	±377	±0.44
	±S	5927	2919	<3.53	14478	61.2	29.2	68.8	2182	1984	4.32
24 JUNE 1987:		±607	±415		±2349	±5.80	±15.1	±29.2	±378	±322	±0.39
HH-Plot		6365	3616	< 3.53	21506	69.9	17.5	169	5252	3032	6.46
(100% DEAD foliage)		10057	3941	< 3.53	22028	103	17.5	08	5522	2945	6.02
LH-Plot		8784	3540	< 3.53	12641	90.2	30.4	146	3422	2106	4.19
C-Plot		6578	2455	< 3.64	9035	68.9	< 5.73	61.6	2117	1404	2.69

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
15 JULY 1987:											
HH-Plot		8878	3696	< 3.53	14784	57.7	18.2	51.9	3348	2440	4.73
LH-Plot		8623	3255	< 3.53	11517	70.8	< 5.56	81.8	2350	1747	4.06
C-Plot	Average	10120	3212	<3.53	9710	67.7	7.87	43.9	2077	1387	3.16
	±S	±1225	±129	-	±460	±10.0	±3.30	±37.30	±297	±55.1	±0.42
2 SEPTEMBER 1987:											
HH-Plot		10188	4527	< 3.53	10246	65.7	< 5.560	34.2	2958	2519	4.90
LH-Plot		10725	3838	< 3.53	9329	95.9	11.5	54.1	2875	2200	1.82
C-Plot		13370	4816	< 3.530	7181	73.4	50.4	86.9	3075	1369	2.45
3 AUGUST 1988:											
HH-Plot		11940	3705	10.9	6192	76.4	42.0	< 0.33	2125	1492	1.85
LH-Plot		16821	2971	15.6	10572	117	44.0	< 0.33	2255	1683	1.97
C-Plot		16142	3257	9.05	10570	121	42.3	< 0.33	2171	1510	1.95
12 JULY 1989:											
HH-Plot	Average	9406	2953	54.6	8781	80.4	141	105.6	2580	1656	2.43
	±S	±3051	±581	±45.4	±1690	±9.7	±79.9	±61.8	±449	±263	±0.50
LH-Plot	Average	8842	2692	59.9	8377	67.3	130	68.6	2513	1522	1.79
	±S	±1931	±467	±50.0	±2869	±14.8	±58.8	±43.4	±1044	±444	±0.19
C-Plot	Average	11781	3423	91.9	9417	80.2	179	56.6	2804	1634	1.92
	±S	±1945	±165	±2.90	±1182	±18.4	±11.9	±3.2	±608	±231	0.02
***Populus tremuloides* stem**											
27 MAY 1987:											
HH-Plot	Average	5902	1636	<3.53	10732	34.5	10.6	25.3	2360	854	1.81
	±S	±2141	±197	-	±3052	±5.98	±8.8	±7.40	±449	±377	±0.72
LH-Plot	Average	5361	1629	18.0	9596	28.7	13.4	46.4	1939	762	1.51
	± S	±501	±115	±26.5	±1625	±3.2	±13.5	±31.9	±279	±101	±0.15
C-Plot	Average	6102	1661	134	7651	36.5	80.7	64.8	1736	816	1.51
	± S	±527	±169	±30.7	±1302	±8.20	±21.7	±22.2	±255	±62.0	±0.10

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
24 JUNE 1987:											
HH-Plot		6957	1755	< 3.53	8865	30.5	16.5	140	1686	845	1.59
LH-Plot		5743	1731	< 3.53	9282	37.6	< 5.56	225	1818	840	1.71
C-Plot		5563	1521	< 3.530	6544	31.0	8.98	39.0	1387	581	1.11
15 JULY 1987:											
HH-Plot		5172	1541	< 3.53	9100	23.8	< 5.56	3.29	1445	655	1.45
LH-Plot		5096	1206	< 3.53	7469	21.7	< 5.56	22.6	1222	577	1.30
C-Plot		4838	1169	< 3.53	6400	19.65	< 5.560	< 0.34	1088	393	0.87
2 SEPTEMBER 1987:											
HH-Plot		4217	1371	< 3.53	7230	25.7	< 5.56	< 0.34	1435	714	1.65
LH-Plot		4274	1468	< 3.53	4467	22.7	< 5.56	55.2	1314	533	1.09
C-Plot		4233	973	< 3.530	3791	23.7	< 5.56	7.78	982	449	0.50
Calamagrostis canadensis aboveground growth											
27 MAY 1987:											
HH-Plot											
'86 growth	Average	3185	583	<3.53	1606	844	12.2	128	817	709	0.96
	± S	±42.9	±51.0	-	±471	±267	±3.69	±17.1	±89.2	±116	±0.14
'87 growth	Average	2757	1488	54.5	36764	1155	10.6	64.6	6521	4147	5.10
	± S	±306	±52.8	±52.3	±2187	±160	±8.71	±30.3	±255	±152	±0.28
LH-Plot											
'86 growth	Average	2578	609	<3.53	972	1064	156	64.0	456	515	0.60
	± S	±450	±181		±254	±42.3	±223	±22.7	±83.6	±80.4	±0.12
'87 growth	Average	2295	1339	5.01	33788	1006	<5.56	64.6	5611	3295	4.90
	± S	±115	±159	±1.51	±1505	±205	-	±4.70	±245	±65.8	±0.41
C-Plot											
'87GROWTH	Average	2150	899	36.0	2496	837	21.7	37.3	3313	2015	3.42
	± S	±587	±61.5	±8.30	±330	±338	±5.31	±19.7	±258	±180	±0.30
'86 growth		2367	397	21.5	662	1296	57.2	29.9	354	397	0.37
24 JUNE 1987:											
HH-Plot		3253	1164	37.7	9555	1110	53.2	170	2499	2149	3.05
LH-Plot		2993	1336	< 3.53	9713	650	58.1	162	2382	1748	2.49
C-Plot		2803	752	4.16	12613	634	11.8	52.9	1926	1442	2.11

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
15 JULY 1987:											
HH-Plot		2245	522	< 3.53	1986	627	< 5.56	74.5	678	589	1.03
LH-Plot		2031	568	< 3.530	7525	592	< 5.560	37.4	1417	1043	1.88
C-Plot	Average	2923	820	8.10	13355	822	6.95	67.5	1993	1307	1.94
	± S	±43	±50	±6.36	±1720	±182	±1.90	±34.7	±164	±163	±0.15
25 SEPTEMBER 1987:											
HH-Plot		-	-	-	-	-	-	-	-	-	--
LH-Plot		2874	785	< 3.53	4405	461	< 5.56	26.1	1085	939	.73
C-Plot		4211	954	< 3.53	7647	1057	33.4	148	518	1060	1.66
3 AUGUST 1988:											
HH-Plot		4392	1489	26.2	19999	125	12.0	63.8	3160	1684	1.74
LH-Plot		3538	1493	17.3	14284	791	85.2	136	2147	1431	1.46
C-Plot		2697	736	21.6	12746	1268	< 5.56	32.2	2074	1546	1.14
12 JULY 1989:											
HH-Plot	Average	3353	1081	<2.52	15105	288	140	86.2	2344	1314	1.53
	±S	±606	±214	-	±1551	±67.9	±9.20	±23.1	±218	±166	±0.05
LH-Plot	Average	3278	1244	<2.50	15652	839	91.5	77.3	2750	1504	2.07
	±S	±24.0	±427	-	±786	±363	±1.40	±5.52	±98.3	±211	±0.25
C-Plot	Average	2936	1078	15.1	14515	793	129	113	2674	1736	1.65
	± S	±242	±119	±22.2	±1342	±123	±24.8	±64.8	±271	±345	±0.08
Fresh litter											
27 MAY 1987:											
HH-Plot	Average	14042	2107	60.8	2611	328	266	364	1055	974	1.67
	±S	±4001	±396	±75.8	±328	±96.7	±226	±190	±201	±310	±0.48
LH-Plot	Average	16805	2374	66.6	2007	365	288	431	1259	1036	1.73
	± S	±4302	±241	±63.0	±323	±89.8	±152	±337	±198	±200	0.32
C-Plot	Average	16613	2140	33.9	2042	260	281	382	1190	913	1.60
	± S	±3801	±430	±30.0	±780	±51.1	±241	±296	±72.0	±46.2	±0.24
24 JUNE 1987:											
HH-Plot		17640	2117	206	2549	342	499	597	1784	1482	3.69
LH-Plot		12685	2387	< 3.53	2152	212	94.1	181	1482	1221	2.47
C-Plot		14886	2040	<3.60	2005	207	136	295	1293	1256	2.27

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
Amelanchier alnifolia foliage											
27 MAY 1987:											
HH-Plot	Average	9645	4757	12.1	25119	577	24.0	640	8280	2266	5.43
	± S	± 230	±203	±12.2	±387	±98.2	±26.1	±10.0	±146	±4.90	±0.13
LH-Plot		7036	4682	< 3.53	24677	422	< 5.56	49.5	7694	2203	5.33
C-Plot		8307	4237	34.8	19696	525	38.8	63.5	6591	1952	4.97
15 JULY 1987:											
HH-Plot		11726	5744	< 3.53	28507	721	46.0	69.1	6947	2463	6.54
LH-Plot		8620	3979	< 3.53	19062	570	< 5.56	27.5	3799	1442	3.92
C-Plot		8038	3462	< 3.53	16055	579	< 5.56	< 0.34	3505	1038	2.94
2 SEPTEMBER 1987:											
HH-Plot		9815	3566	9.66	21451	637	< 5.56	79.8	4258	2014	2.44
LH-Plot		11403	4897	< 3.53	18199	1034	< 5.56	15.23	4764	1391	1.94
C-Plot		13427	4491	< 3.53	10151	1018	43.4	128	4999	1028	2.04
3 AUGUST 1988:											
HH-Plot		14411	4917	19.0	20020	665	49.6	197	4420	1806	2.62
LH-Plot		14245	4442	8.30	14113	719	42.8	< 0.34	4118	1354	1.93
C-Plot		11502	4165	10.9	15804	776	36.1	< 0.34	4278	1160	1.87
Amelanchier alnifolia stem											
27 MAY 1987:											
HH-Plot	Average	6362	1121	<3.53	5063	224	29.2	20.4	1239	469	1.34
	± S	±514	±175		±859	±40.3	±18.5	±28.4	±358	±79.2	±0.20
LH-Plot		6701	1003	< 3.530	3923	203	< 5.56	16.2	620	341	0.88
C-Plot		7182	947	27.4	4715	215	21.8	< 0.34	1128	479	1.22
15 JULY 1987:											
HH-Plot		7765	1790	< 3.53	6345	205	8.30	11.62	1646	558	1.30
LH-Plot		6327	1331	< 3.53	5428	155	< 5.56	2.71	904	323	1.08
C-Plot		5963	972	< 3.53	4110	134	< 5.56	< 0.34	672	244	0.87

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
2 SEPTEMBER 1987:										
HH-Plot	5499	1291	< 3.53	6692	106	< 5.56	< 0.34	1291	543	0.73
LH-Plot	4728	1031	< 3.53	3757	142	< 5.56	< 0.34	857	392	1.08
C-Plot	6465	1277	< 3.53	3309	222	6.35	46.7	837	395	0.90
***Viburnum edule* foliage**										
27 JULY 1987:										
HH-Plot	15055	4338	13.8	26958	49.3	187	110	3845	1719	4.68
LH-Plot	11586	3211	< 3.53	25203	30.9	115	52.6	2415	1010	2.65
C-Plot	14691	2799	< 3.53	25081	30.3	268	53.6	3113	1102	2.44
2 SEPTEMBER 1987:										
HH-Plot	6303	1369	< 3.53	13126	29.4	< 5.56	104	1339	650	0.74
LH-Plot	12333	3448	< 3.53	19897	58.8	37.3	9.34	2650	940	1.85
C-Plot	18428	3354	< 3.53	17548	55.8	254	85.2	2692	571	1.12
3 AUGUST 1988:										
HH-Plot	14727	3693	9.43	28283	49.4	110	0.34	4019	1092	1.78
LH-Plot	12928	3216	3.96	26581	50.8	176	< 0.34	2855	1003	1.55
C-Plot	16044	3612	6.60	22370	77.5	325	< 0.34	3999	1187	1.38
***Viburnum edule* stem**										
15 JULY 1987:										
HH-Plot	9906	1699	24.9	11970	34.5	58.6	36.8	1344	646	1.32
LH-Plot	9358	1150	< 3.53	11718	11.7	47.5	2.80	988	405	0.79
C-Plot	7364	1072	< 3.53	11032	19.6	< 5.56	17.0	779	391	0.95
2 SEPTEMBER 1987:										
HH-Plot	12617	4305	< 3.53	19861	53.3	68.5	86.0	2386	1197	1.20
LH-Plot	7019	1293	< 3.53	10706	27.0	< 5.56	< 0.34	1183	551	1.30
C-Plot	8504	1146	< 3.53	9243	25.4	39.6	80.4	1025	458	0.88

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
***Rosa acicularis* foliage**										
27 MAY 1987:										
HH-Plot	10471	4916	< 3.53	24223	275	< 5.56	102	7336	3124	5.61
LH-Plot	11495	4629	8.14	20720	245	< 5.56	8.6	6994	2857	5.21
C-Plot	11969	4365	92.7	21543	212	136	355	6861	2399	4.26
15 JULY 1987:										
HH-Plot	11138	4860	< 3.53	26114	149	47.2	100	5621	2800	5.34
LH-Plot	11114	4601	< 3.53	17316	107	< 5.56	9.4	3916	2479	3.32
C-Plot	14207	4550	< 3.53	16190	323	66.7	38.9	3748	2432	3.02
2 SEPTEMBER 1987:										
HH-Plot	11955	4887	< 3.53	14044	137	< 5.56	87.2	4062	2419	5.06
LH-Plot	9809	4377	< 3.53	13656	141	< 5.560	7.50	3789	2486	3.39
C-Plot	11351	3880	< 3.53	9211	394	33.7	61.4	2094	1180	1.87
3 AUGUST 1988:										
HH-Plot	11879	4209	< 3.53	13148	185	128	< 0.34	3037	2061	2.02
LH-Plot	12250	4442	< 3.53	15611	92.5	43.6	49.2	3546	2498	2.00
C-Plot	15064	4323	< 3.53	17333	356	47.9	51.7	4149	2423	1.65
***Rosa acicularis* stem**										
15 JULY 1987:										
HH-Plot	7853	1583	< 3.53	8592	123	< 5.56	28.0	1237	663	1.45
LH-Plot	6257	1397	< 3.53	7350	62.1	< 5.56	5.19	1011	425	1.08
C-Plot	8912	1776	< 3.53	9220	142	17.4	29.2	1222	474	0.88
2 SEPTEMBER 1987:										
HH-Plot	6174	1227	< 3.53	4842	57.4	< 5.56	56.3	868	373	0.96
LH-Plot	4696	1217	< 3.53	4068	86.3	5.56	0.34	708	339	0.81
C-Plot	7031	1191	< 3.530	3886	258.3	136	112	729	371	0.79

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
***Salix* spp foliage**										
27 MAY 1987:										
HH-Plot	13082	4871	< 3.53	29288	178	< 5.56	99.5	8996	4086	7.68
LH-Plot	11466	4383	56.9	23968	93.1	57.7	139	7182	3520	6.97
C-Plot	9236	2607	18.7	15875	128	32.3	109	4086	2073	4.41
15 JULY 1987:										
HH-Plot	8625	4234	3.53	39091	131	5.56	80.9	8156	5008	8.85
LH-Plot	8164	2923	< 3.53	12368	129	< 5.560	23.6	2312	2159	4.14
C-Plot	13351	3024	< 3.53	12273	185	31.5	146	2616	1691	3.22
2 SEPTEMBER 1987:										
HH-Plot	10716	3972	<3.53	22631	11.4	<5.56	<0.34	2321	3402	4.89
LH-Plot	14319	4073	< 3.53	11498	125	< 5.56	< 0.34	2039	1803	2.62
C-Plot	10702	3140	< 3.57	11293	304	29.8	54.7	1941	1665	2.36
3 AUGUST 1988:										
HH- Plot	-	-	-	-	-	-	-	-	-	-
LH- Plot	-	-	-	-	-	-	-	-	-	-
C-Plot	9924	2881	40.3	11439	186	44.0	48.5	3428	1932	1.83
***Salix* spp stem:**										
27 MAY 1987:										
HH-Plot	7414	1050	4.92	5576	58.9	28.1	13.0	1195	676	1.19
LH-Plot	7133	1151	60.5	5871	43.9	34.1	68.2	1149	632	1.29
C-Plot	5867	928	20.0	7674	83.3	25.4	43.5	1404	656	1.24
15 JULY 1987:										
HH-Plot	6561	1103	< 3.53	7778	29.5	< 5.56	< 0.34	865	667	1.30
LH-Plot	5237	1111	< 3.53	8513	46.7	< 5.56	< 0.34	1168	733	1.35
C-Plot	7925	937	< 3.53	7305	56.9	30.6	7.45	1163	517	0.86

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
2 SEPTEMBER 1987:										
HH-Plot	4009	720	<3.53	2993	32.1	<5.56	<0.34	928	515	0.92
LH-Plot	4160	756	< 3.53	3097	54.1	< 5.56	< 0.34	680	386	0.79
C-Plot	4658	853	< 3.53	2770	83.7	7.11	34.1	906	430	0.82
Alnus crispa foliage										
15 JULY 1987:										
HH-Plot	8280	2749	< 3.53	10531	356	< 5.56	50.1	2252	1869	4.48
LH-Plot	8879	2649	< 3.53	8842	292	<5.56	68.1	2353	1920	4.32
C-Plot	9016	2482	< 3.60	9537	321	55.8	34.7	2402	1765	4.60
3 AUGUST 1988:										
HH-Plot	.	.	.	.	.	.	.	.	.	.
LH-Plot	.	.	.	.	.	.	.	.	.	.
C- Plot	9072	2344	37.3	12768	502	61.0	80.2	2321	1913	3.17
Alnus crispa stem										
15 JULY 1987:										
HH-Plot	5370	1559	< 3.53	8422	238	< 5.56	59.0	1814	1028	2.46
LH-Plot	5422	1602	<3.53	7895	196	<5.56	42.0	1616	989	2.36
C-Plot	6835	1445	< 3.53	6831	227	6.12	20.2	1749	917	2.36
Shepherdia canadensis foliage										
15 JULY 1987:										
HH-Plot	4867	2445	< 3.530	19564	41.1	< 5.56	67.9	2030	2180	5.27
LH-Plot	5224	2251	< 3.53	19610	55.0	< 5.56	27.2	1830	1929	5.02
C-Plot	8120	2994	< 3.53	17381	82.0	29.1	91.0	1544	1863	4.64
2 SEPTEMBER 1987:										
HH-Plot	4610	2169	< 3.53	18541	58.4	< 5.56	51.1	2005	3277	5.12
LH-Plot	5929	2295	< 3.53	19074	86.6	< 5.56	31.0	1056	1628	3.45
C-Plot	6716	1501	< 3.530	15066	87.2	28.2	74.1	1369	857	2.91

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
3 AUGUST 1988:										
HH-Plot	7548	2648	61.2	17307	76.8	98.9	175	1820	1962	2.97
LH-Plot	8387	2891	45.8	19226	97.7	72.0	137	1881	2089	3.06
C-Plot	7675	2911	49.9	14195	77.5	49.1	70.7	1818	1971	2.99
***Shepherdia canadensis* stem**										
15 JULY 1987:										
HH-Plot	1995	568	< 3.53	5338	18.3	17.4	50.4	841	754	2.48
LH-Plot	1202	444	< 3.53	6465	11.9	< 5.56	18.1	836	642	2.54
C-Plot	1748	539	< 3.53	5552	18.7	< 5.56	< 0.34	840	674	2.52
2 SEPTEMBER 1987:										
HH-Plot	1287	582	< 3.53	4789	13.7	< 5.56	32.5	818	1016	2.52
LH-Plot	1181	367	< 3.53	4242	15.9	< 5.56	< 0.34	725	652	2.16
C-Plot	1677	462	< 3.53	4422	22.9	7.71	34.0	903	603	2.18
***Corylus cornuta* foliage:**										
15 JULY 1987:										
HH-Plot	12286	3800	< 3.53	13426	613	22.4	87.3	3068	1917	4.79
LH-Plot	11944	3143	9.31	9958	696	73.8	65.1	2030	1427	3.53
C-Plot	9664	2905	< 3.5	9840	348	< 5.56	34.8	1890	1263	3.71
2 SEPTEMBER 1987:										
HH-Plot	12360	3550	< 3.53	13806	524	23.8	120	4785	1723	4.68
LH-Plot	10056	2441	< 3.53	8306	456	< 5.56	33.8	1887	920	2.18
C-Plot	14803	3128	< 3.53	9702	1076	94.2	111	2011	801	1.53
3 AUGUST 1988:										
HH-Plot	12226	3020	39.39	9141	525	62.4	80.2	2311	1537	2.36
LH-Plot	11581	2317	34.8	10011	350	55.9	80.8	2418	1713	2.38
C-Plot	12757	2787	35.0	9961	710	71.3	77.4	3041	1235	1.81

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
***corylus cornuta* stem**										
15 JULY 1987:										
HH-Plot	7642	1895	< 3.53	9351	316	< 5.56	31.7	963	590	1.54
LH-Plot	9830	1697	25.6	8609	508	38.9	24.7	1102	613	1.54
C-Plot	7139	1501	< 3.53	7776	217	< 5.56	68.2	792	497	1.38
2 SEPTEMBER 1987:										
HH-Plot	6733	1431	< 3.53	7684	386	< 5.56	104	1014	556	1.70
LH-Plot	5697	985	< 3.53	6301	333	< 5.56	< 0.34	685	448	1.14
C-Plot	11365	1233	< 3.53	5796	652	6.35	41.8	812	483	1.22
***Cornus canadensis* foliage**										
15 JULY 1987:										
HH-Plot	18270	6265	< 3.53	13492	57.2	277	53.0	2910	2644	3.06
LH-Plot	25096	7754	< 3.530	11965	72.2	433	215	3603	3318	2.78
C-Plot	26390	7051	28.6	12776	90.4	563	35.2	3143	2167	2.34
2 SEPTEMBER 1987:										
HH-Plot	16838	5341	< 3.53	11852	66.2	307	41.5	2383	1973	2.90
LH-Plot	34101	8642	111	9162	95.9	627	166	2925	2860	1.63
C-Plot	26084	6383	< 3.530	9473	108	537	40.4	2172	1739	1.58
3 AUGUST 1988:										
HH-Plot	19348	6241	73.4	13989	66.9	341	221	2457	1900	1.13
LH-Plot	30340	8339	73.7	12364	99.3	472	80.1	3594	2273	1.40
C-Plot	29486	7119	40.7	12364	118	712	68.8	3306	2252	1.32
***Cornus stolonifera* foliage**										
15 JULY 1987:										
HH-Plot	19945	3522	<3.53	10222	23.5	<5.56	122	2342	2745	2.52
LH-Plot	20423	3965	< 3.53	9724	34.8	< 5.56	30.2	2438	3165	2.84
C-Plot	23492	3643	10.3	9649	47.3	<5.56	56.7	2287	2989	2.35

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
2 SEPTEMBER 1987:										
HH-Plot	23136	3673	< 3.53	9120	53.8	32.2	96.5	3124	4691	3.21
LH-Plot	23722	3899	<3.53	8722	26.0	<5.56	55.7	2876	3455	2.87
C-Plot	27073	4123	16.2	8631	23.7	<5.56	44.5	2902	3578	2.31
3 AUGUST 1988:										
HH-Plot	27009	5301	< 3.53	10394	124	65.8	79.3	2553	5170	2.02
LH-Plot	24365	3741	5.84	8991	47.3	40.7	53.3	3023	2329	1.64
C-Plot	26015	3981	<3.53	8473	31.7	55.1	61.9	2801	2675	1.73
***Cornus stolonifera* stem**										
15 JULY 1987:										
HH-Plot	6987	1165	<3.53	5542	31.1	<5.56	<0.34	122?	765	0.98
LH-Plot	7250	1042	< 3.53	5756	11.3	< 5.56	< 0.34	1122	536	0.91
C-Plot	7560	998	<3.53	4987	23.4	<5.56	< 0.34	1055	567	0.87
2 SEPTEMBER 1987:										
HH-Plot	9228	1635	6.98	4827	38.8	16.2	211	1894	819	1.14
LH-Plot	-	-	-	-	-	-	-	-	-	-
C-Plot	9765	1234	<3.53	4476	32.1	<5.56	<0.34	1722	572	0.86
***Galium boreale* foliage plus stem**										
15 JULY 1987:										
HH-Plot	9650	2507	< 3.53	32136	68.2	< 5.56	56.3	3146	2000	4.86
LH-Plot	13739	3051	< 3.53	24483	124	36.2	65.1	2883	1699	3.16
C-Plot	11390	2517	< 3.53	22512	95.2	< 5.56	7.75	1447	950	2.30
2 SEPTEMBER 1987:										
HH-Plot	17394	3744	45.6	18430	173	65.8	140	3208	1836	4.74
LH-Plot	21891	4508	148	16417	266	178	211	2772	1439	2.37
C-Plot	13798	2711	11.1	13855	166	83.3	86.9	1120	696	1.48

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
3 AUGUST 1988:										
HH-Plot	16171	4411	30.3	18646	148	68.0	73.5	1660	1122	1.47
LH-Plot	17023	4056	10.5	20595	125	56.2	64.9	1636	1069	1.41
C-Plot	17601	3054	11.8	22001	209	52.6	62.8	1385	1073	1.23
Castilleja miniata **foliage plus stem**										
15 JULY 1987:										
HH-Plot	10550	3695	< 3.53	44689	74.0	< 5.56	64.4	6609	3135	5.05
LH-Plot	9405	2551	< 3.53	36683	51.3	26.8	63.9	4886	1528	2.76
C-Plot	6841	2295	< 3.530	36954	91.3	< 5.56	< 0.34	3828	1348	2.41
2 SEPTEMBER 1987:										
HH-Plot	16723	3977	<3.53	31243	87.5	< 5.56	78.9	6901	2856	4.55
LH-Plot	20388	4665	103	29005	102	152	144	6010	2208	2.45
C-Plot	17688	4577	<3.53	30165	119	79.9	<0.34	3467	1449	1.98
3 AUGUST 1988:										
HH- Plot	11520	2823	< 3.53	36627	95.0	37.7	47.81	4860	1685	1.04
LH-Plot	10225	2441	14.7	26944	84.5	37.0	38.2	3679	1224	0.80
C-Plot	12354	2615	15.6	42550	98.1	27.7	41.3	3516	1172	0.80
Epilobium angustifolium **foliage plus stem**										
27 MAY 1987:										
HH-Plot	11903	5374	< 3.53	21376	151	< 5.56	72.5	7214	2610	5.73
LH-Plot	11024	5344	21.6	18411	170	< 5.56	62.8	5884	2321	5.19
C-Plot	12654	5344	85.9	18368	175	51.2	28.6	4822	1945	4.62
15 JULY 1987:										
HH-Plot	9200	4685	< 3.53	27466	163	< 5.56	64.6	6099	2382	5.52
LH-Plot	12896	4015	17.7	18913	146	51.7	107	4003	1252	3.05
C-Plot	10138	3289	< 3.53	7614	138	< 5.56	< 0.34	3642	1067	3.38

APPENDIX C (continued)

Species and plant part		Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
						mg/kg					
2 SEPTEMBER 1987:											
HH-Plot		14887	4616	< 3.53	8109	260	< 5.56	38.7	2609	1409	3.20
LH-Plot		15372	5468	68.1	11997	255	130	193	4976	1424	2.52
C-Plot		16667	3801	56.6	6115	326	87.8	76.4	2713	1355	0.69
3 AUGUST 1988:											
HH-Plot		14704	3050	< 3.53	16104	82.3	46.4	67.2	2700	1244	2.03
LH-Plot		12746	3154	7.35	19890	63.8	57.6	68.4	3288	1330	2.13
C-Plot		14232	4938	28.6	12323	124	84.0	69.1	3058	1008	1.54
12 JULY 1989:											
HH-Plot	Average	12618	3736	3.66	13878	143	67.7	62.8	3967	1228	1.93
	± S	±1026	±578	±2.31	±1795	±23.8	±9.68	±15.1	±351	±66.4	±0.08
C-Plot	Average	13250	4077	10.5	16979	143	67.9	66.9	3741	1401	2.20
	± S	±2342	±479	±2.80	±4140	±25.0	±14.4	±10.6	±245	±119	±0.23
LH-Plot	Average	12486	4076	< 2.53	15114	138	75.3	60.6	4194	1344	2.15
	± S	±79.2	±498		±1818	±8.33	±6.86	±5.44	±380	±66.0	±0.05
Lathyrus ochroleucus **foliage plus stem**											
15 JULY 1987:											
HH-Plot		6642	2821	< 3.53	30029	75.4	< 5.56	38.8	2229	1930	5.52
LH-Plot		7079	2811	< 3.53	22631	70.5	< 5.56	48.8	1239	1163	3.45
C-Plot		6432	2502	< 3.53	23413	75.7	< 5.56	< 0.34	1366	1250	4.06
2 SEPTEMBER 1987:											
HH-Plot		7149	2301	< 3.53	16273	64.2	< 5.56	23.3	2113	1640	4.88
LH-Plot		12985	3828	61.7	13089	228	268	487	2080	1971	4.59
C-Plot		-	-	-	-	-	-	-	-	-	-
3 AUGUST 1988:											
HH- PLot		15913	3593	22.6	20286	108	38.9	61.0	2172	1661	2.80
LH-Plot		13418	2877	18.0	21003	67.9	34.6	67.9	1823	1564	2.70
C-Plot		10129	2692	8.48	20909	122	42.2	63.7	1711	1661	2.69

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
Vicia americana **foliage plus stem**										
15 JULY 1987:										
HH-Plot	7656	2421	< 3.53	23686	63.6	< 5.56	97.8	2366	1643	5.04
LH-Plot	9053	2650	< 3.53	20892	74.8	< 5.56	1.66	1595	1324	4.16
C-Plot	8923	3017	< 3.53	23279	107	< 5.56	42.3	1949	1487	4.62
2 SEPTEMBER 1987:										
HH-Plot	7840	2584	< 3.53	15035	83.9	< 5.56	155	2046	1606	4.98
LH-Plot	10135	3048	28.1	10672	81.0	112	212	1680	1605	3.08
C-Plot	-	-	-	-	-	-	-	-	-	-
3 AUGUST 1988:										
HH-Plot	13084	3434	19.8	18710	82.4	43.8	61.7	2051	1629	2.37
LH-Plot	12774	3109	11.6	17942	104	42.2	74.4	1840	1587	2.49
C-Plot	12623	3007	23.5	19151	179	42.9	61.0	1745	1542	2.66
Aralia nudicaulis **foliage**										
15 JULY 1987:										
HH-Plot	9694	2704	< 3.53	24607	490	< 5.56	62.8	3187	2328	3.87
LH-Plot	7736	2149	< 3.53	24433	443	< 5.56	9.16	2292	1383	2.52
C-Plot	7485	2152	< 3.53	20218	451	< 5.56	15.8	2222	968	2.74
2 SEPTEMBER 1987:										
HH-Plot	15337	3159	< 3.53	13961	1374	< 5.560	70.1	2937	2582	1.16
LH-Plot	18068	3282	14.5	11500	1013	356	610	2593	2580	1.09
C-Plot	19044	3149	<3.53	10887	1104	229	86.9	2089	896	0.93
3 AUGUST 1988:										
HH-Plot	11243	2614	< 3.53	19633	602	38.1	70.3	2610	1201	1.58
LH-Plot	11733	2045	11.6	19550	495	40.6	80.3	2453	1380	1.63
C-Plot	11933	2444	10.1	18533	744	44.1	81.5	2149	994	1.28

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
Aster ciliolatus **foliage plus stem**										
15 JULY 1987:										
HH-Plot	8876	3035	< 3.53	64915	70.1	< 5.56	60.7	5769	2480	4.90
LH-Plot	9681	2800	< 3.53	66996	81.7	< 5.56	49.3	5039	1587	3.83
C-Plot	12426	2951	< 3.53	53421	102	35.1	73.2	3713	1057	2.07
2 SEPTEMBER 1987:										
HH-Plot	-	-	-	-	-	-	-	-	-	-
LH-Plot	12975	3350	< 3.53	64321	139	< 5.56	43.9	3616	1461	2.94
C-Plot	14864	3285	< 3.53	51599	102	55.6	44.2	2522	1063	2.01
3 AUGUST 1988:										
HH-Plot	12400	2898	39.4	57664	103	63.0	117	5430	1862	2.36
LH-Plot	12770	2717	23.9	45076	105	36.7	67.8	2705	1051	1.60
C-Plot	13245	2766	5.77	44347	119	23.6	59.2	2345	1009	1.30
Spiraea betulifolia **foliage plus stem**										
15 JULY 1987:										
HH-Plot	-	-	-	-	-	-	-	-	-	-
LH-Plot	5536	2511	< 3.53	15195	409	< 5.56	< 0.34	2740	1187	2.18
C-Plot	5788	2318	< 3.530	11373	598	< 5.56	3.91	1747	858	1.90
2 SEPTEMBER 1987:										
HH-Plot	-	-	-	-	-	-	-	-	-	-
LH-Plot	9527	3606	11.6	11478	686	59.4	113	2823	1267	2.10
C-Plot	9651	3386	10.7	8236	1007	35.9	73.6	1545	679	1.31
3 AUGUST 1988:										
HH- Plot	7838	3812	30.9	20943	468	42.0	63.9	3228	1376	1.91
LH-Plot	12966	5483	16.5	19154	1001	53.5	57.2	3984	2151	2.00
C-Plot	11233	4987	13.2	13651	345	24.3	65.7	1865	754	1.21

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
***Lonicera dioica* foliage**										
3 AUGUST 1988:										
HH-Plot	13720	3463	< 3.53	22396	63.9	30.6	33.6	3348	1369	1.75
LH-Plot	21713	4613	< 3.530	20098	74.9	41.5	40.1	2492	1425	1.66
C-Plot	23569	4007	5.65	29423	87.7	49.0	38.0	4014	1398	1.46
***Lonicera involucrata* foliage**										
15 JULY 1987:										
HH-Plot	11428	4315	< 3.53	44357	169	< 5.56	82.7	8755	3963	7.21
LH-Plot	10967	4592	<3.53	28765	123	<5.56	54.6	6231	3657	4.43
C-Plot	11488	4121	< 3.53	23781	32.1	40.4	43.6	4817	3370	2.40
2 SEPTEMBER 1987:										
HH-Plot	14026	3689	9.43	23362	30.4	152	395	7004	4041	3.33
LH-Plot	18026	4756	5.84	27304	79.4	68.8	350	5430	5346	2.11
C-Plot	14578	4538	21.3	21617	57.1	65.9	49.0	3168	3268	1.26
3 AUGUST 1988:										
HH-Plot	14022	3970	< 3.530	23184	30.1	48.9	62.7	3376	2319	1.77
LH-Plot	10435	3182	< 3.530	18859	22.7	38.4	38.7	2421	2088	1.51
C-Plot	12600	3514	5.09	22577	56.3	39.9	41.4	3036	2721	1.25
***Lonicera involucrata* stem**										
15 JULY 1987:										
HH-Plot	5887	1633	< 3.53	5832	287	< 5.56	60.7	702	576	0.90
LH-Plot	5347	1725	<3.53	6143	187	<5.56	52.3	713	532	0.61
C-Plot	5043	1507	7.90	6839	112	24.3	56.7	765	392	0.58

APPENDIX C (continued)

Species and plant part	Ca	Mg	Na	K	Mn	Al	Fe	P	S	% total N
					mg/kg					
2 SEPTEMBER 1987:										
HH-Plot	9946	3247	< 3.53	4614	156	29.9	110	346	1321	1.26
LH-Plot	5607	1856	< 3.530	5215	174	40.5	127	901	513	0.76
C-Plot	4805	1334	< 3.530	4873	229	19.2	< 0.34	661	391	0.69

[a]All dates are time of collection of samples, hexazinone was applied as PRONONE 10G on 28 August 1986.

[b]HH = high herbicide (4 kg hexazinone/ha); LH = low herbicide (2 kg hexazinone/ha); C = control, no treatment.